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NOMINATION

OF THE

CITY RAILWAY SYDNEY

AS A

NATIONAL ENGINEERING LANDMARK

The official trial train at St James Station on the eastern section of Sydney's new City Railway, 9 December 1926. Dr J. J. C. Bradfield, Chief Engineer, Metropolitan Railway Construction and Sydney Harbour Bridge Branch, is standing third from the train.

Submission from the
Engineering Heritage Committee
Sydney Division, I. E. Aust.
Prepared by Dr. Don Fraser F I E Aust

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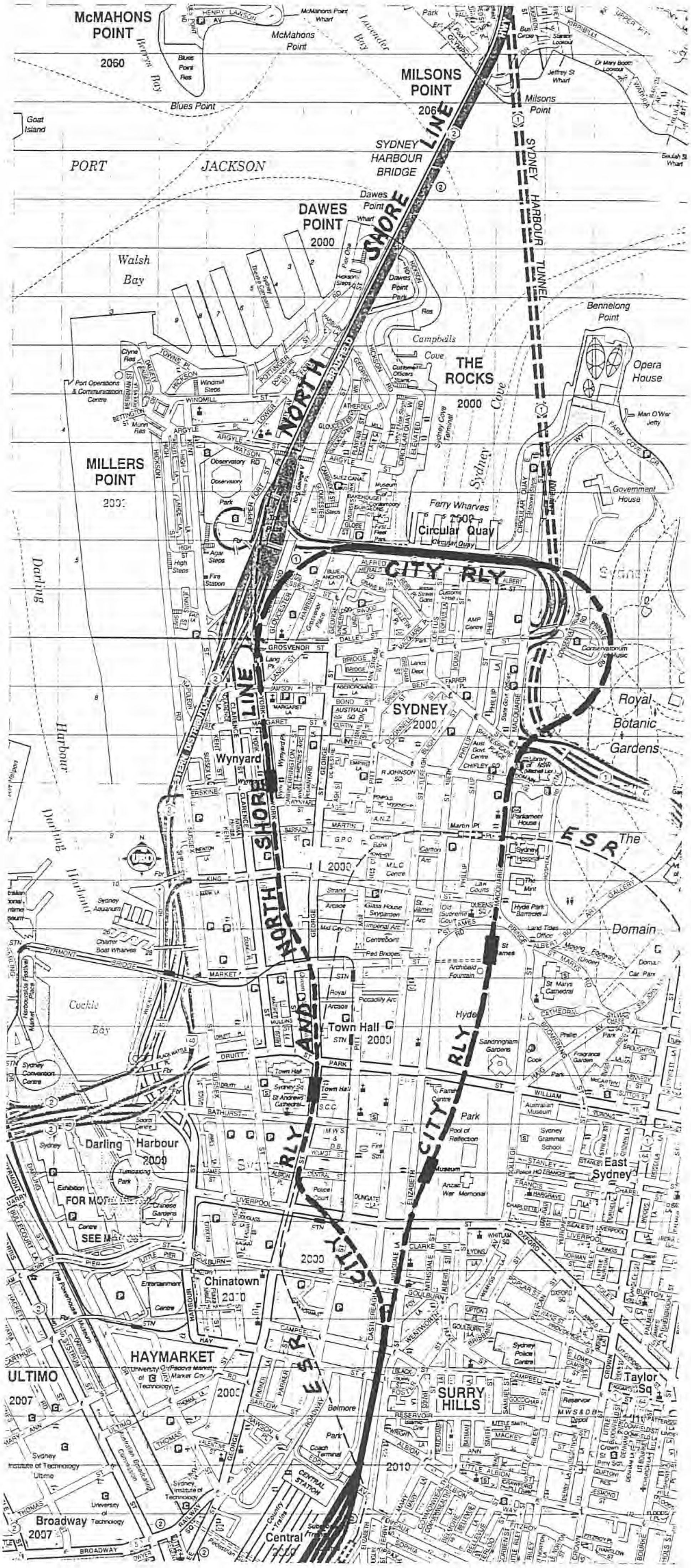


Location Map

STATEMENT OF SIGNIFICANCE

Sydney's City Railway is the 15th city railway constructed in the world out of the 17 built before World War II. Of the total of 65 city railways in the world, most were built after World War II.

Sydney had its City Railway operating in 1926 ahead of other major cities such as Moscow (1930), Chicago (1943), Rome (1955), San Francisco (1972) and Hong Kong (1979).

Although a relatively small city railway, Sydney's is comparable to many other city railways in size, engineering infrastructure and use of technology.

Without the city railway, the City of Sydney would have choked on the congestion in its streets, seriously affecting its long term survival as a major trading centre for Australia. The railway enabled Sydney to remain a major business and commercial centre which brought enormous economic rewards to Australia.

It was the first underground city railway in Australia and the only one for 55 years. It set the pattern, eventually followed by Melbourne with the opening of its city loop railway in 1981. Other Australian capital cities have railways stations only on the fringes of their Central Business Districts.

The city railway has also been of significant social benefit for people working in the city, for shoppers and for visitors and tourists because of the ease of mobility it provides for moving around the city centre.

The City Railway allowed suburban rail services to be separated from the country services which greatly reduced the passenger train congestion at Sydney Station. This separation and the link into the city allowed significant improvements to be made to the suburban rail services.

The sound planning and construction combined with improving railway technology has enabled the City Railway to cope with patronage that has virtually doubled during its 70 years of operation.

The City Railway is strongly associated with one of Australia's most famous engineers, J. J. C. Bradfield.

SYDNEY'S CITY RAILWAY AND WORLD METROS

WHAT IS A METRO ?

From Paul Garbutt's book *World Metro Systems* the following extracts illustrate and define a Metro.

> Metropolitan railways, designed to carry large numbers of city dwellers, workers and visitors, originated in London early in the second half of the last century. As a result of the Industrial Revolution and Britain's position as the hub of a vast mercantile empire, London had become the largest city in the world, and its central thoroughfares were jammed with horse-drawn cabs, coaches and drays, and thronged with pedestrians. Suburban railways already existed to carry people to and from the central zone, but a new kind of railway was needed to distribute them within the city itself. (page 5)

> Large cities require both outer-suburban type lines and inner-suburban or metro type lines. The former are usually multi-tracked with stations not closely spaced. They 'funnel' passengers to the central zone. The latter distribute the passengers locally within the central area of the city, including peak-hour traffic brought in by the outer-suburban services and the main line railways. Metro lines are usually separate pairs of tracks with stations at frequent intervals and all trains normally serve all stations. (page 20)

> The classic metro system is a high-capacity network which serves the central area and inner suburbs of a city. It is automatically signalled and possibly automatically operated, the platforms are at car floor level and there is easy passenger interchange with other transport services. (page 10)

Sydney's City Railway meets these criteria.

Although small compared to some of the famous metros of the world (London, Paris, New York, Moscow) Sydney's City Railway is comparable with many other city metros and predates most of them, as shown in the following table. Garbutt's book has descriptions and illustrations of the world metros which have details that are either identical to or very similar to Sydney's system.

WORLD METROS

Decade	City or cities
1860s	London (1863)
1890s	Budapest (1896), Glasgow (1896), Vienna (1898)
1900s	Paris (1900), Boston (1901), Berlin (1902), New York (1904), Athens (1904), Hamburg (1906), Philadelphia (1908)
1910s	Buenos Aires (1913), Madrid (1919)
1920s	Barcelona (1924), **SYDNEY (1926)**, Tokyo (1927)
1930s	Moscow (1930)
1940s	Chicago (1943)
1950s	Stockholm (1950), Toronto (1954), Cleveland (1955), Rome (1955), Lisbon (1959)
1960s	Kiev (1960), Milan (1964), Oslo (1966), Montreal (1966), Baku (1967), Frankfurt (1968), Rotterdam (1967), Mexico City (1969), Beijing (1969)
1970s	Munich (1971), San Francisco (1972), Yokohama (1972), Nuremburg (1972), Seoul (1974), Sao Paulo (1974), Prague (1974), Kharkov (1975), Washington (1976), Vienna (1976), Brussels (1976), Kobe (1977), Amsterdam (1977), Lyon (1978), Marseille (1978), Atlanta (1979), Bucharest (1979), Hong Kong (1979), Rio de Janeiro (1979)
1980s	Newcastle-on-Tyne (1980), **MELBOURNE (1981)** Kyoto (1981), Helsinki (1982), Baltimore (1983), Caracas (1983), Lille (1983), Manila (1984), Miami (1984), Calcutta (1984), Minsk (1984), Cairo (1987), Singapore (1987), Instanbul (1989)

Source - *World Metro Systems* by Paul Garbutt pp 140-147.

HISTORICAL REVIEW

INTRODUCTION

There is a huge amount of information written about Sydney's City Railway, from Royal Commission Reports as early as 1891 through to sections of books such as John Gunn's 1988 *Along Parallel Lines - A history of the railways of New South Wales, 1850-1986.*

It is not the intention in this nomination report to cite all references nor quote from a large number of them, but two definitive papers from the 1926 Transactions of the Institution of Engineers, Australia are attached to back of this submission. One by the then Chief Commissioner for Railways, James Fraser, gives a contemporary overview of Sydney's suburban railway system, and the second is a detailed description of the the City Railway by its famous proponent Dr. J. J. C. Bradfield.

What follows is a short historical summary based on notes supplied by the Manager Archives, State Rail Authority of NSW.

THE CITY RAILWAY, SYDNEY

During the 1890s there was much public discussion and two Royal Commissions about a possible extension of the railway from the then Sydney Terminal Station on the southern side of Devonshire Street, into the city proper. This would enable city workers to travel direct to the city by train and avoid the necessity of changing to a tram to complete their journeys. Various schemes were proposed including an above ground steam railway to Circular Quay and a new rail terminus in Hyde Park.

What might be said to be the commencement of specific action was in January 1912 when the Minister for Works set up the Sydney Harbour Bridge and City Transit Department, with J. J. C. Bradfield in charge, to investigate the problems of city and suburban rail travel. In January 1914 Bradfield travelled overseas to study city transit systems and long span bridges. On his return, he submitted a report in February 1915 in which he recommended a City Railway, an Eastern Suburbs Railway and new railways to serve the the western and northern suburbs. All were to be electric railways and the City Railway was to be an underground railway. The Act authorising the construction of the underground railway was passed on 13 October 1915.

Work began in February 1916 under a contract with Messers Norton, Griffith & Company. They began the elevated section between the new Central electric stations and the Goulburn Street portals, some tunnelling under city buildings, the cut and cover tunnels behind the Conservatorium of Music and the Macquarie Street overbridge where the loop railway would start its crossing of Circular Quay. The contract was cancelled in 1917 and the work was continued by the Department of Railways staff. Construction ceased in June 1918 and was resumed in February 1922.

The eastern side of the City Railway was completed to St James station and rail services began on 20 December 1926 to ease the congestion caused by the Christmas shopping rush. The western side of the City Railway was built jointly with the North Shore Line which continued north to cross the Sydney Harbour Bridge, also under Bradfield's supervision. The City Railway stopped at Wynyard and rail services began on 28 February 1932. The link across Circular Quay was yet to be constructed.

Work on the Circular Quay Station and its approaches commenced in 1936 but stopped during the 1939-45 war period. Work resumed in 1952 and the "loop' was opened for rail services on 20 January 1956. The regular use of the whole city railway, with the through running of outer-suburban trains, began two days later and has continued ever since.

Bradfield's 1926 paper, at the back of this submission, contains detailed descriptions of all the engineering work of the City Railway. But a summary is given here which, together with the map at the front of this document, will enable the reader to gain an appreciation of the scale of the project.

The underground railway consists of two components, the City Railway and the North Shore Line. Both start at the northern side of the Central electric stations and involve six tracks, two for the North Shore Line, two for the City Inner and two for the City Outer. The six tracks proceed from Central via an elevated embankment between tall stone-faced retaining walls and bridging over Eddy Avenue, Hay Street and Campbell Street, till they enter tunnels at Goulburn Street.

On the east side, two tracks of the City Railway pass under city buildings, Elizabeth and Liverpool Streets to enter Museum Station. The tunnels are shallow, just under the foundations of the city buildings and the streets above, so careful time-consuming underpinning work was necessary, described in K. A. Fraser's paper *Methods of Tunnelling on the City of Sydney underground railway* and A. H. D. Humphries' paper

Flat top and special tunnel construction, details of underpinning buildings (both in I E Aust Transactions, 1930).

Museum Station was built by the cut and cover method. The two straight tracks and flanking platforms are contained under a reinforced concrete barrel roof of 48 feet (15 m) span and 520 feet (158 m) long. The tracks leave Museum Station by a double-track tunnel but soon enter single-track tunnels and proceed north to St James Station. There are other tunnels under Hyde Park, built to Bradfield's Eastern Suburbs Railway plans but they have never been used.

St James Station is located at the northern end of Hyde Park, 40 feet (12 m) below the restored level of the park. It was built as a multi-platform station because of the planned Eastern Suburbs tracks. The buried structure consists of reinforced concrete barrel roofs over single tracks and a large steel frame for the station building proper.

The two tracks continue north under Macquarie Street before swinging east then around a long curve under the Botanic Gardens and clear of the Conservatorium of Music (all cut and cover construction) to reach the eastern portal at Circular Quay.

Circular Quay Station is a large reinforced concrete frame 25 feet (8 m) above Alfred Street. The station is located in the centre of the valley with ferry wharves to the north and busses (originally trams) to the south. The approach viaducts consist of double-track steel plate web girders on concrete piers taken down to bedrock. The Cahill Expressway, overhead, is supported by a series of steel portal frame which in turn are supported by the railway piers and the station framework.

The two tracks then enter a double-track tunnel on the western side of Circular Quay and swing south to reach Wynyard Station. This is a dual line station, so we return to Central and describe the work from there, along the western side of the city, to the Sydney Harbour Bridge.

At Central, the four western tracks, 2 North Shore and 2 City Railway, swing west after the Goulburn Street portals and head diagonally under buildings and city streets (more difficult underpinning work) then straighten up under George Street to enter Town Hall Station. This is a three line station because Bradfield's plan allowed for the Eastern Suburbs Railway to pass through this station as well as the North Shore Line and the City Railway. This eventually came to pass when the ESR was completed in 1979.

Town Hall Station is a 5-storey steel frame built in a deep long pit excavated in the middle of George Street. Road and tram traffic were diverted around each side of the excavation but were restored to the middle of the road as soon as the steelwork had reached a stage when the concrete roof could support the traffic loads. There are six tunnels at each end of Town Hall Station at levels not compatible with the platform levels at Central and at Wynyard, so there was some intricate construction required to pass the tunnels above or below each other to reach their correct destinations. The Eastern Suburbs tunnels swing away east to Martin Place and the other four tracks proceed to Wynyard where another buried steel building forms the station.

Most of Wynyard Square and York Street were excavated and then restored over the concrete roof. At this stage the two North Shore tracks are the upper pair and proceed north along single-track tunnels to the Harbour Bridge, whereas the two lower tracks are those of the City Railway and connect to the tracks coming in from Circular Quay.

The City Railway, the Sydney Harbour Bridge and the Electrification of the Suburban Railways took 10 years to build (excepting the late construction of the Circular Quay link), cost many millions of pounds and were the largest coordinated railway works in Australia's history. The scale of the civil, mechanical and electrical engineering work was enormous, even by world standards, and incorporated the latest technologies of the day.

SOCIAL IMPACT

The following notes were obtained from railway experts on the social history and operations of Sydney's City Railway, as acknowledged by the Australian Railway Historical Society.

Robert Gibbons

Until 1890, railway construction had been primarily intended to promote country commerce. In that year the first specifically suburban line (the North Shore) was opened. By 1896 the metropolitan system was largely complete and the steam trains did, in a sense, provide genuine suburban services. They were the fastest mode of transport with the longest average journey.

But the trains stopped at the southern end of the city. From there, people had to use trams or walk to their destinations further north. Serious congestion in the city streets developed, caused by the high frequency of trams from Central Station and from the suburbs serviced by the tram system.

The major problems with the train system were caused by the lack of an inner city terminus and no railway crossing of the harbour. The 1908 Royal Commission into the Improvement of the City of Sydney and its Suburbs recommended, among others, that the major gaps in the existing railway system be filled, namely, a completely separate underground city rail loop and the city be connected to the North Shore by some means, preferably a bridge.

Ian Brady

Hordes of people were on the city streets prior to the city railway, mostly walking to and from Central station where the suburban trains terminated. Trams to this station used the ramps leading up to the concourse level and during the peak hours the trams were doubled-up.

The greatest impact of the City Railway was moving the people off the streets and transporting them underground to their city destinations.

Tram patronage dropped off dramatically after the City Railway began operating..

Shops were concentrated near the railway stations, around Central Square at the southern end of the city, and around the northern arc of the city railway loop (Museum, St James, Wynyard and Town Hall). The region between Central and Bathurst Street became a retail no-mans land and has continued to be so through to the present.

But the Central Business District and the downtown retail shopping area (north of Bathurst Street) prospered enormously. After the city railway reached St James in 1926, David Jones built their 1928 Elizabeth Street store across the road from the station entrance. After World War II the high-rise building development of Sydney took place within that northern arc bounded by Museum, St James, Wynyard and Town Hall stations.

When the Circular Quay link was completed, transport east-west across the city by underground trains became more convenient and safer for many pedestrians, than walking, for example from Wynyard to St James.

Tony Swift

The completed City Railway greatly improved travel within the city. It allowed passengers on an "east side" train to stay on board and travel to the west side of the city, and vice versa.

The Circular Quay link effectively connected the ferry services at the northern end of the city to the southern end, particularly to the country trains at Central.

Simon Foster

St James Station became a great benefit to the north-east side of the city with better access to the main shopping district, to the medical specialist in Macquarie Street and for special events held in the Domain. Overall this encouraged people to leave their cars at home or at a suburban railway station.

Patronage of the City Railway has maintained parity with the general population increase, for example, in 1932 some 1,300,00 people passed through St James and in 1992 that number was 2,056,000. As for the trams, congestion on the city streets and falling patronage saw them removed by 1961 and replaced by the more flexibly operated buses.

EFFECT ON TRAIN OPERATIONS

The same railway experts have indicated that there was a mixed effect of advantages and disadvantages with the City Railway, compounded by changing technologies and train operating practices, but overall train operations and services between the suburbs and the city have improved.

Sydney's City Railway is often referred to as the City Circle, but it is not a circular railway like the Circle Line in London which operates almost independently of the other lines, consequently London's Circle Line is relatively isolated from problems on the other underground lines.

Sydney's City Railway is an open circle with trains passing through the city and out again just like the Paris Metro and the New York Subway, consequently, problems on the outer parts of the system can seriously affect operations in the city. But train controllers do their best to minimise delays and interruptions.

Prior to completion of the Circular Quay link, driver change overs and reversing of trains at the dead-ends at Wynyard and St James was reasonably efficient. The link provided the benefit of through-running but the extra distance meant that more time was involved. However, overall, there was greater flexibility in train operations through the city with better timetabling and more frequent services.

CONCLUSION

The overriding consensus after 70 years experience, is that without the City Railway, the inner city of Sydney would not have become the vibrant heart of the metropolis that it is today. It would have choked on its own congestion with a relocation, long ago, of many of its functions to other regions - suburbia, country regions or interstate. Melbourne recognised these dangers more than twenty years ago and in 1981 completed its city loop railway linking the main stations of Flinders Street and Spencer Street, on its city fringe, to the city centre.

State Rail Authority of New South Wales

Level 7 MSB Building
201-207 Kent Street, Sydney NSW 2000
GPO Box 29, Sydney NSW 2001
Telephone: (02) 224 2330
Facsimile: (02) 224 3566

11 July 1995

Mr Donald Fraser
14 Derby Street
Vaucluse NSW 2030

Dear Don,

Following our meeting at St James yesterday I have made enquiries to confirm certain details regarding the works in progress and the options for installing the commemorative plaque.

Ian Brady shares the view we formed on site that the most appropriate place for the plaque will be opposite the ticket windows where there will be a suitable alcove between kiosks and an available wall surface. The station upgrading manager has been informed and will be pleased to assist with the installation.

The present upgrading works are behind schedule and now due for completion in December this year. I trust this date will suit your group.

You should be aware that State Rail is committed to the preservation of St James Station. The present upgrading works, including the reinstatement of the cream and green wall tiles, are being undertaken to ensure that the Station can continue to function as a principal underground station with due recognition of its heritage significance. If the National Committee on Engineering Heritage of the Institute of Engineers accepts your recommendation to mark the place with the NEL plaque this will serve to further increase public awareness of the significance of the place.

Yours sincerely,

Donald Ellsmore
Heritage Manager

Commemorative Plaque Nomination Form

Date....July 1995.........

From....Engineering.........

Heritage Committee,

Sydney Division, IE Aust

Nominating Body

To:
Commemorative Plaque Sub-Committee
The Institution of Engineers, Australia
Engineering House
11 National Circuit
BARTON ACT 2600

The following work is nominated for a:-

- * National Engineering Landmark
- * ~~Historic Engineering Marker~~

*(delete as appropriate)

Name of work......City Railway - Sydney.........

Location, including address and map grid reference if a fixed work.............

......In and around the City of Sydney.........

....

Owner.....State Rail Authority of NSW.........

....

The owner has been advised of the nomination of the work and has indictated (attach a copy of letter if available)........letter attached.........

....

Access to site.......Only by train and at stations.........

Future care and maintenance of the work....It is a working part of.........

......Sydney's railway network - long life assured.........

Name of sponsor........N/A.........

For a NEL, is an information plaque required?..........Yes.........

....

Chairperson of Nominating Committee

.........[signature]......17/7/95.........

Chairperson of Division Heritage Committee/Panel

ADDITIONAL SUPPORTING INFORMATION

Name of work...City Railway - Sydney...

Year of construction or manufacture...1916 to 1918 and 1922 to 1932...

Period of operation...1926 to the present and continuing...

Physical condition...Excellent...

Engineering Heritage Significance:-

Technological/scientific value...State-of-the-art railway technology in 1926...

Historical value...First city railway in Australia...

Social value...Carries millions of passengers to and around the city centre per year

Landscape or townscape value...N/A it's mostly underground...

Rarity...First of 2 in Australia, No 15 in the world...

Representativeness...Typical of smaller city railways elsewhere in world...

Contribution to the nation or region...Allowed Sydney's growth to continue...

Contribution ot engineering...One of largest engineering projects in Australia

Persons associated with the work...Dr. J.J.C. Bradfield...

Integrity...All features intact...

Authenticity...Almost entirely as built, except signalling upgrading...

Comparable works(a) in Australia...Melbourne 1981...

(b) overseas...15th built out of 65 in world...

Statement of significance, its location in the supporting documentation......

See previous to this nomination

Citation (70 words is optimum)...

See after this nomination

Attachments to submission (if any)...Nil...

Proposed location of plaque (if not at site)...St James Station...

PROPOSED WORDS ON THE INFORMATION PLAQUE

Version 1

SYDNEY'S CITY RAILWAY

WHEN OPENED TO ST JAMES STATION IN 1926, THIS UNDERGROUND ELECTRIFIED RAILWAY WAS THE FIRST TO ENTER AN AUSTRALIAN CAPITAL CITY SPECIFICALLY TO SERVE THE CITY CENTRE. THE SCHEME WAS LARGELY DUE TO DR J J C BRADFIELD OF SYDNEY HARBOUR BRIDGE FAME AND INVOLVED A MASSIVE AMOUNT OF ENGINEERING WORK, TUNNELS, STATIONS AND BRIDGES. THE CITY LOOP ACROSS CIRCULAR QUAY WAS COMPLETED IN 1956 AND THE SYSTEM HAS BECOME AN ESSENTIAL COMPONENT OF SYDNEY'S RAILWAY NETWORK.
(75 words)

DEDICATED BY
THE INSTITUTION OF ENGINEERS, AUSTRALIA
AND THE STATE RAIL AUTHORITY OF NSW. 1995

Versions 2 and 3 on next pages

Version 2

THE CITY RAILWAY
SYDNEY

THIS UNDERGROUND ELECTRIFIED RAILWAY WAS THE FIRST CITY RAILWAY IN AUSTRALIA WHEN OPENED TO ST JAMES STATION IN 1926. THE WYNYARD SECTION WAS OPENED IN 1932 AND CLOSING THE LOOP ACROSS CIRCULAR QUAY WAS COMPLETED IN 1956. THE SCHEME WAS LARGELY DUE TO DR J J C BRADFIELD OF SYDNEY HARBOUR BRIDGE FAME AND INVOLVED A MASSIVE AMOUNT OF ENGINEERING WORK. IT HAS BEEN A BOON TO SYDNEY AND PASSENGER CAPACITY HAS DOUBLED DURING ITS 70 YEARS OF OPERATION.
(77 words)

DEDICATED BY
THE INSTITUTION OF ENGINEERS, AUSTRALIA
AND THE STATE RAIL AUTHORITY OF NSW. 1995

Version 3

SYDNEY'S CITY RAILWAY

THIS FIRST UNDERGROUND RAILWAY IN AUSTRALIA WAS OPEN TO ST JAMES ON 21ST DECEMBER 1926 FROM CENTRAL VIA MUSEUM. IT WAS THE EASTERN PART OF THE LOOP. THE WESTERN SECTION TO WYNYARD WAS OPENED IN 1932 AND THE TWO LINKED AT CIRCULAR QUAY STATION IN 1956. THE SCHEME WAS LARGELY PLANNED BY DR J J C BRADFIELD OF SYDNEY HARBOUR BRIDGE FAME. IT REQUIRED MASSIVE ENGINEERING WORKS AND HAS BEEN A BOON TO THE CITY DURING ITS SEVENTY YEARS OF OPERATION.
(80 words)

DEDICATED BY
THE INSTITUTION OF ENGINEERS, AUSTRALIA
AND THE STATE RAIL AUTHORITY OF NSW. 1995

BRADFIELD, JOHN JOB CREW (1867-1943), civil engineer, was born on 26 December 1867 at Sandgate, Queensland, fourth son of John Edward Bradfield, labourer and Crimean War veteran, and his wife Maria, née Crew. His parents, brothers and four sisters had arrived in Brisbane from England in 1857. Educated at the North Ipswich State School and the Ipswich Grammar School on a scholarship, Bradfield passed the Sydney senior public examination in 1885, gaining the medal for chemistry. Dux of his school, he won a

Queensland government university exhibition and in 1886 matriculated at the University of Sydney. From St Andrew's College, he continued his brilliant academic career, graduating B.E. with the University Gold Medal in 1889.

From May, Bradfield worked as a draftsman under the chief engineer, railways, in Brisbane. On 28 May 1891 at St John's Pro-Cathedral he married Edith Jenkins. That year he was retrenched and joined the New South Wales Department of Public Works as a temporary draftsman, becoming permanent in 1895. An associate from 1893 of the Institution of Civil Engineers, London, he graduated M.E. with first-class honours and the University Medal in 1896. He had been a founder of the Sydney University Engineering Society in 1895 and was president in 1902-03 and 1919-20. In his 1903 presidential address he drew attention to the competition, initiated in 1900, for the design of a bridge across Sydney Harbour; there had been agitation for a bridge or tunnel since the 1880s.

Bradfield was associated with a great range of engineering work including the Cataract Dam near Sydney and the Burrinjuck Dam which formed part of the Murrumbidgee Irrigation Area. In January 1909 he was promoted assistant engineer at a salary of £400. He had worked on some important projects, but he was not his own master. In August 1910 he applied for the foundation chair of engineering in the new University of Queensland, but was unsuccessful despite twenty-two testimonials from senior public servants, academics, engineers and architects such as Norman Selfe [q.v.6.], (Sir) George Knibbs, (Sir) Edgeworth David, R. F. Irvine and (Sir) John Sulman [qq.v.].

In February 1912 in evidence to the Parliamentary Standing Committee on Public Works Bradfield proposed a suspension bridge to connect Sydney and North Sydney, but in April also submitted a cantilever design. Next year the committee recommended acceptance of his scheme for the construction of a cantilever bridge from Dawes Point to Milsons Point. In 1913 his title was changed to chief engineer for metropolitan railway construction.

Plans for a city railway were already well developed by his predecessors when, in 1914, Bradfield went overseas to investigate new approaches to metropolitan railway construction. Early next year he reported on the proposed electric lines for the city of Sydney. Aware that a bill was soon to come before parliament, he went to considerable effort to show the practicality of his scheme. He was at his most convincing in this report, as in all his later publications, when he managed to combine both the functional and the 'city beautiful' aspects of his plan. In the debates on the bill, his engineering talents were praised by both sides. However all sections of his scheme were postponed as a general war economy measure.

In October 1913, with J. D. Fitzgerald [q.v.] and Sulman, Bradfield had attended the inaugural meeting of the Town Planning Association of New South Wales; at the first Australian Town Planning Conference and Exhibition held in Adelaide in October 1917, he argued in his paper, 'The transit problems of greater Sydney', that his scheme of suburban electrification would benefit large property owners, new home purchasers and the general public by opening up new land, with quicker transport and cheaper fares. He predicted that Sydney's population would reach at least 2 226 000 by 1950. Bradfield maintained – apparently without reprimand from government – an extraordinary barrage of articles and public addresses advocating his plan.

In March 1922 he was sent overseas to inquire into tenders for a cantilever bridge. Later that year the Harbour Bridge Act was carried; Bradfield had advised R. T. Ball [q.v.] to amend the bill to provide for either a cantilever or an arch bridge, according to his specifications, as developments in light steel made the latter possible. In 1924 he recommended that the government should accept the tender of Dorman Long & Co. of Middlesbrough, England.

The easy passage of the Harbour Bridge Act undoubtedly increased Bradfield's determination to promote other sections of his scheme. By mid-1923 the public could see results of the Bradfield plan in the massive excavations and tunnel-building in Hyde Park for the underground railway. In 1924 he received the first doctorate of science in engineering awarded by the University of Sydney, for a thesis entitled 'The city and suburban electric railways and the Sydney Harbour Bridge'. One of his examiners, Sir John Monash [q.v.], wrote: 'these works are undoubtedly of exceptional magnitude, being in some respects unique in Engineering practice'. The opening of the St James and Museum stations and the new section of the Central Station at Chalmers Street on 20 December 1926 marked his plan's first result. In February 1930 he was curtly retired by the railway commissioners; however cabinet preserved his status in the Department of Public Works and £3000 salary, and he continued to represent the government in dealings with the contractors and to supervise construction of the bridge.

During this extended period of public and parliamentary exposure Bradfield's expertise was never questioned. But in 1929 con-

troversy flared over who really designed the bridge, inspired by a series of articles in the *Sydney Morning Herald* by (Sir) Ralph Freeman (1880-1950), consulting engineer to Dorman Long, who was described by the *Herald* as 'the designer' of the bridge and who conveyed the same impression in his articles. Ball, now minister for lands, said it was difficult to determine what was really meant by the term 'designer'; he would describe the bridge as a Bradfield-Dorman Long design. E. A. Buttenshaw [q.v.] called for a report on the matter from Bradfield, who wrote, 'I originated the cantilever bridge design recommended by the public works committee in 1913 and subsequently the arch bridge design of 1650 feet span'; he went on to say Freeman was not the designer and that tenders were called on his own design. The controversy was never finally resolved, but when Bradfield retired in 1933, the director of public works stated that Bradfield was the designer of the bridge and that 'no other person by any stretch of imagination, can claim that distinction'. However, modifications had been made to the design after Freeman's visit in 1926, and in 1932 Dorman Long threatened to sue the government if it erected a plaque naming Bradfield as the designer. One informed view was that the 'detail design was entrusted to Lawrence Ennis who became first Honorary Member of the Institution [of Engineers, Australia] in 1932'. Professor Crawford Munro also considered that Bradfield 'did not design the Sydney Harbour Bridge which we now behold'.

The highlight of Bradfield's career undoubtedly was the opening of the bridge on 19 March 1932 (despite the antics of Captain de Groot of the New Guard). He was a member of the official party and the governor Sir Philip Game [q.v.] named the bridge highway after him. The Depression was to suspend the Bradfield plan for well over a decade, and the construction of the Eastern Suburbs railway was far in the future. In 1933 he was appointed C.M.G. and he retired from the public service in July.

In 1934 Bradfield was appointed consulting engineer for the design, fabrication and construction of a bridge and approaches across the Brisbane River from Kangaroo Point to Bowen Terrace. The Story [q.v.] Bridge was a symmetrical cantilever of 1463 ft. (446 m) in length, with a clear span of 924 ft. (281.6 m); construction began in 1935 and the bridge was opened in 1940. He was also technical adviser to the constructors of the Hornibrook Highway near Brisbane and helped to plan and design the University of Queensland's new site at St Lucia; the university admitted him to an *ad eund.* doctorate of engineering in 1935.

Although in most respects severely pragmatic, Bradfield had a penchant for the grandiose that was revealed in some of his wilder plans for high-rise office blocks astride the southern approaches of the Harbour Bridge and in his proposals for a massive water-diversion scheme in Queensland. In his early seventies he put considerable time and energy into publicizing a plan to irrigate the western districts of Queensland and part of Central Australia by damming certain coastal rivers and running water-pipes through the Great Dividing Range. Aspects of this scheme, and especially his lack of scientific evidence, were publicly attacked by G. W. Leeper of the school of agricultural science at the University of Melbourne.

Bradfield had wide interests within his chosen profession. Early in 1916 he was appointed by the New South Wales government to a committee to establish and manage a school of aviation at Richmond. In 1919 he was a founder of the Institution of Engineers, Australia, and as a councillor in 1920-24 and 1927 represented it on the Australian Commonwealth Standards Association; he was also a member of the Australian National Research Council. He always maintained close links with the University of Sydney: he was a member of its senate in 1913-43, a trustee of Wesley College in 1917-43, a councillor of the Women's College from 1931, and from 1942 deputy chancellor. He was a member of the University Club and from 1922 of the Royal Society of New South Wales.

Bradfield regularly attended St John's Church of England, Gordon, and was a keen gardener. He died at his home at Gordon on 23 September 1943 and was buried in St John's cemetery; a memorial service was held at St Andrew's Cathedral. He was survived by his wife, five sons and a daughter; his youngest son Keith inherited his father's interest in aviation and was assistant director general, Department of Civil Aviation, in 1957-68. Bradfield's estate was valued for probate at £13 843: his salary had been 'by no means commensurate' with his importance. A portrait by F. W. Leist [q.v.] is at the University of Sydney, and others by Gerard Nathan and Joseph Wolinski are held by descendants.

Bradfield was small in stature, with a quiet and humorous disposition. His life was one of total professional zeal and commitment, and he became an outstanding Australian engineer in his generation. Florence Taylor [q.v.] noted his 'tremendous faith in his ability which is not a conceit when there is an enormous knowledge behind that faith and ability'. He was honoured by the award of the (Sir) Peter Nicol Russell [q.v.6] Medal by the Institution of Engineers, Australia, in 1932, the (W. C.) Kernot [q.v.5] Memorial Medal by the University of Melbourne in 1933, and the Telford Gold Medal of the Institution of Civil Engineers, London, in 1934. His vision of Sydney captured the imagination of many, including J. T. Lang [q.v.] who later wrote: 'Bradfield wanted to be the Napoleon III of Sydney. He wanted to pull down everything in the way of his grandiose schemes. He was always thinking of the future. He was probably the first man to plan for Sydney as a city of two million people'.

J. T. Lang, *I remember* (Syd, 1956); A. H. Corbett, *The Institution of Engineers, Australia* (Syd, 1973); P. Spearritt, *Selected writings of Sydney planning advocates, 1900-1947* (Canb, 1973); Univ Syd Union, *Union Recorder*, 30 Sept, 14 Oct 1943; G. W. Leeper, 'Restoring Australia's parched lands . . .', *Aust Q*, June 1942; E. J. Brady, 'Wizard of construction', *Life Digest*, May 1949; *Sydney Mail*, 8 Mar 1922; *SMH*, 6 May 1924, 12 Oct, 17 Nov 1927, 11-14, 23, 25, 28 Mar, 23 Nov 1929, 11, 12, 28 Feb, 12 June 1930, 17 Mar, 29 July 1933, 16 June 1934, 24 Sept 1943; P. Spearritt, The consensus politics of physical planning in Sydney (B.A. Hons thesis, Univ Syd, 1972); Bradfield technical papers (ML, NL, NSWA), *and* Engineering School, Univ Syd); Public Works Dept, Special bundles 4/7582-7588 (NSWA); information from and family papers held by Dr K. N. E. Bradfield.

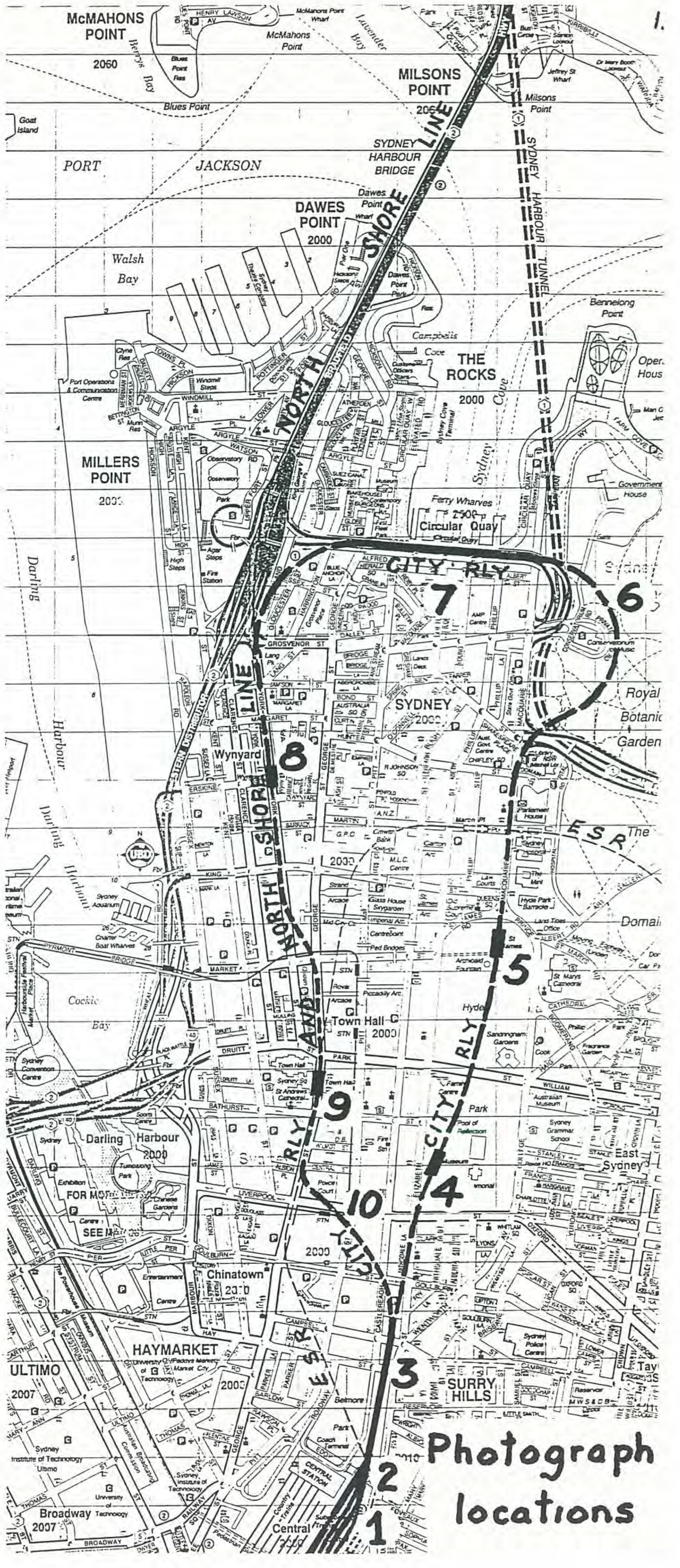
PETER SPEARRITT

PHOTOGRAPHS

OF

SYDNEY
CITY RAILWAY
CONSTRUCTION

Supplied by
Victor Poljanski
Manager Archives
State Rail Authority, NSW.



Photograph locations

Photo location 1 - The Flyovers on the southern side of Central electric station are a clever item of railway engineering. They allows city-bound trains on the upper levels the flexibility of platform selection and city circle operation, independent of the out-ward bound trains on the lower level, which also have their flexibility of operations.

Photo location 2 - Construction in February 1925 of the 7-track wide bridge over Eddy Avenue. The 1906 country and suburban station building, with its clock tower is in the background.

Photo location 2 - Reinforced concrete for railway bridges was still a new development in the 1920s. By March 1925, the slab reinforcement was in place for the Eddy Avenue bridge.

Photo location 2 - The completed Eddy Avenue railway bridge, October 1925, has the appearance of stone eliptical arches but is in fact a 5-span continuous reinforced concrete structure. Under the slab there are parallel ribs of varying depth. It was an innovative design at the time.

Photo location 3 - North of Eddy Avenue, the elevated City Railway crosses over Hay and Campbell Streets. In order to make the intrusive railway visually attractive, Bradfield decided to used stone faced eliptical barrel arches in reinforced concrete.

Photo location 3 - The completed Hay Street arch in July 1924 shows the success of Bradfield's attention to aesthetics for the major engineering components of the City Railway.

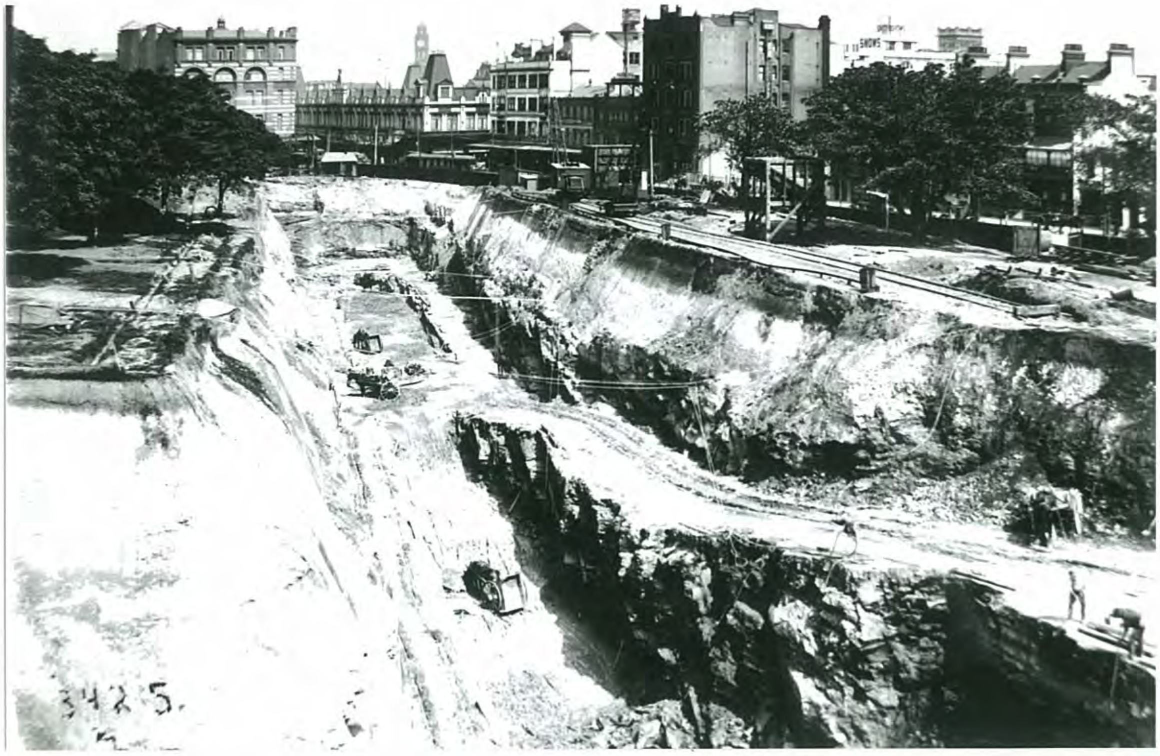


Photo location 4 - Construction of the City Railway through Hyde Park was by cut and cover. The excavation work for Museum Station occupied most of 1922.

Photo location 4 - Museum Station only had to accommodate two straight railway tracks therefore a reinforced concrete barrel roof was a suitable cover. Construction was well advanced in November 1923. Access between platforms and the street was by concrete passageways.

Photo location 4 - Museum Station is located on the corner of Elizabeth and Liverpool Streets. Covering the concrete arch roof took place during 1924.

Photo location 4 - Museum Station in November 1926 ready for the regular use.

Photo location 5 - St James Station is located at the northern end of Hyde Park with access to Elizabeth Street and Queens Square. Excavation was completed in March 1923.

Photo location 5 - St James is a multi-track station, so the tunnel sections were achieved by multi-span barrel roof construction in reinforced concrete, completed by the end of 1924.

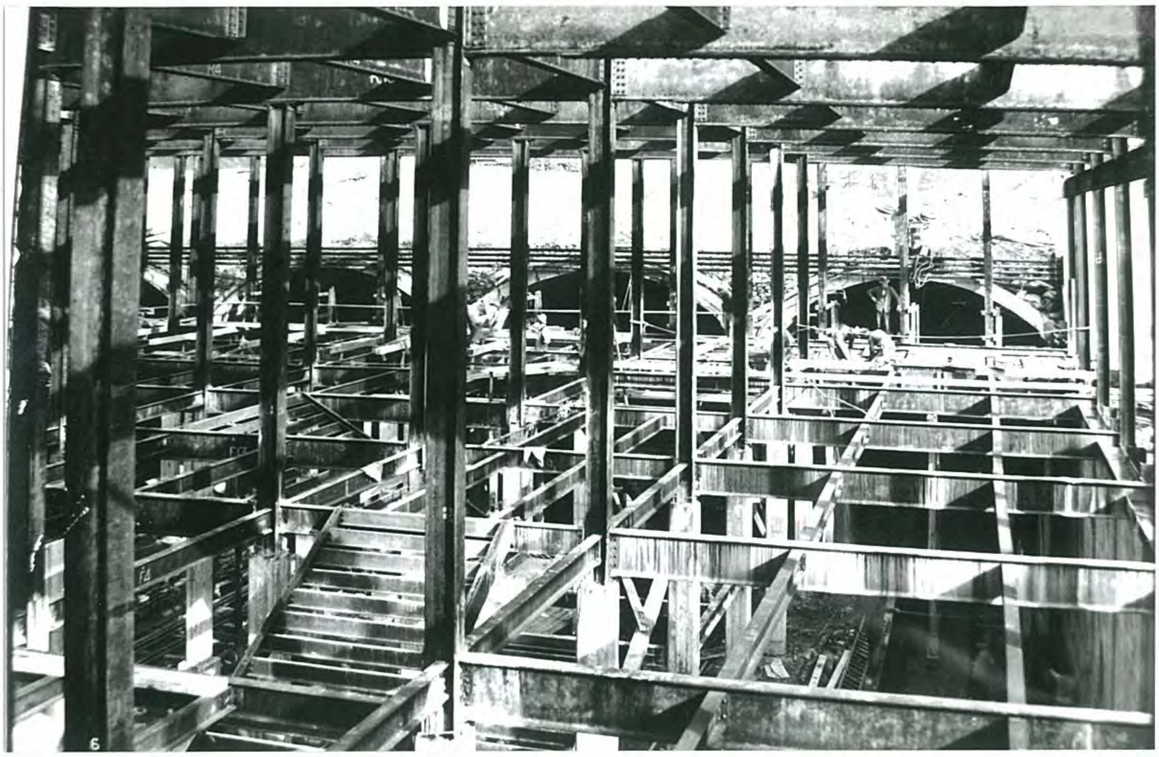


Photo location 5 - The main station building at St James is a conventional steel frame and was erected during 1925.

Photo location 5 - Interior of the completed St James Station in August 1926. The railway tracks were laid soon after. The station was opened on 19th December in time for the Christmas shopping rush.

Photo location 6 - Work on some parts of the City Railway began as early as 1917 but were suspended due to the World War. The right angle turn from Macquarie Street into Circular Quay involved a wide curve behind the Conservatorium of Music.

Photo location 7 - Circular Quay in 1939. City Railway construction was suspended from 1932 to 1952, so completing the loop across Circular Quay did not take place until 1956.

Photo location 7 - Construction of Circular Quay Station and the railway approach viaducts during the 1950s.

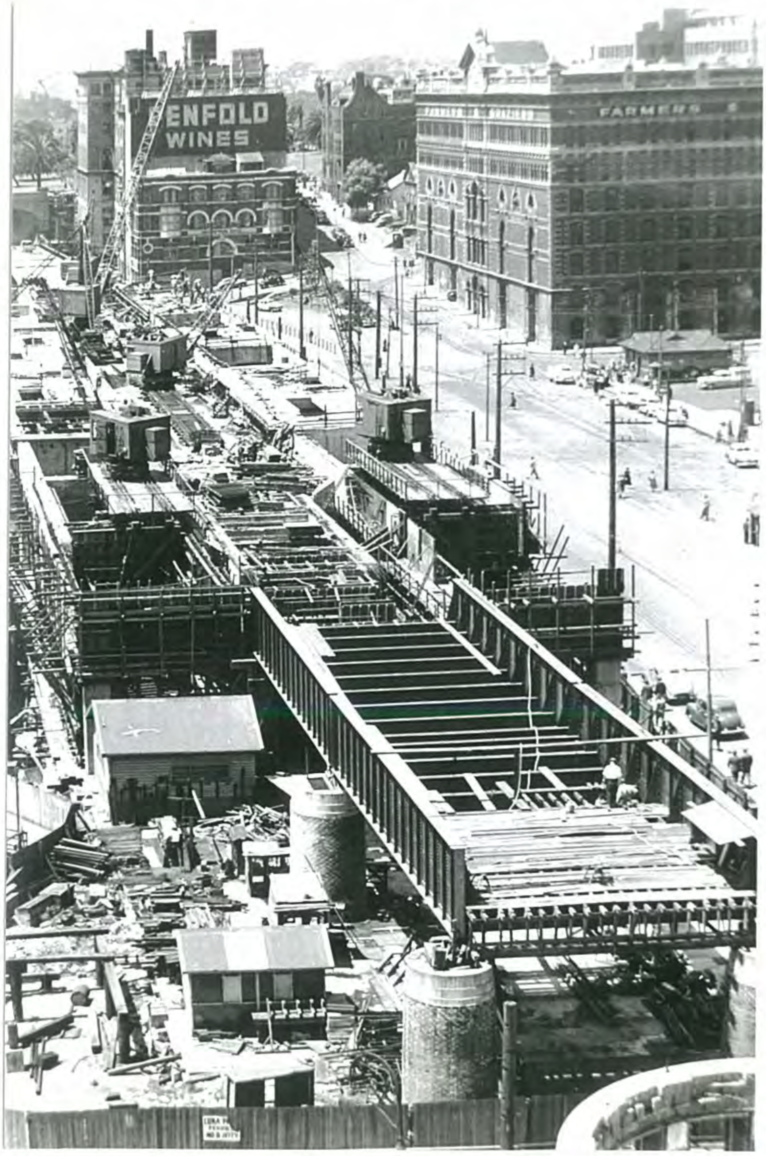


Photo location 7 - Construction of Circular Quay Station and railway approach viaducts in 1954-55.

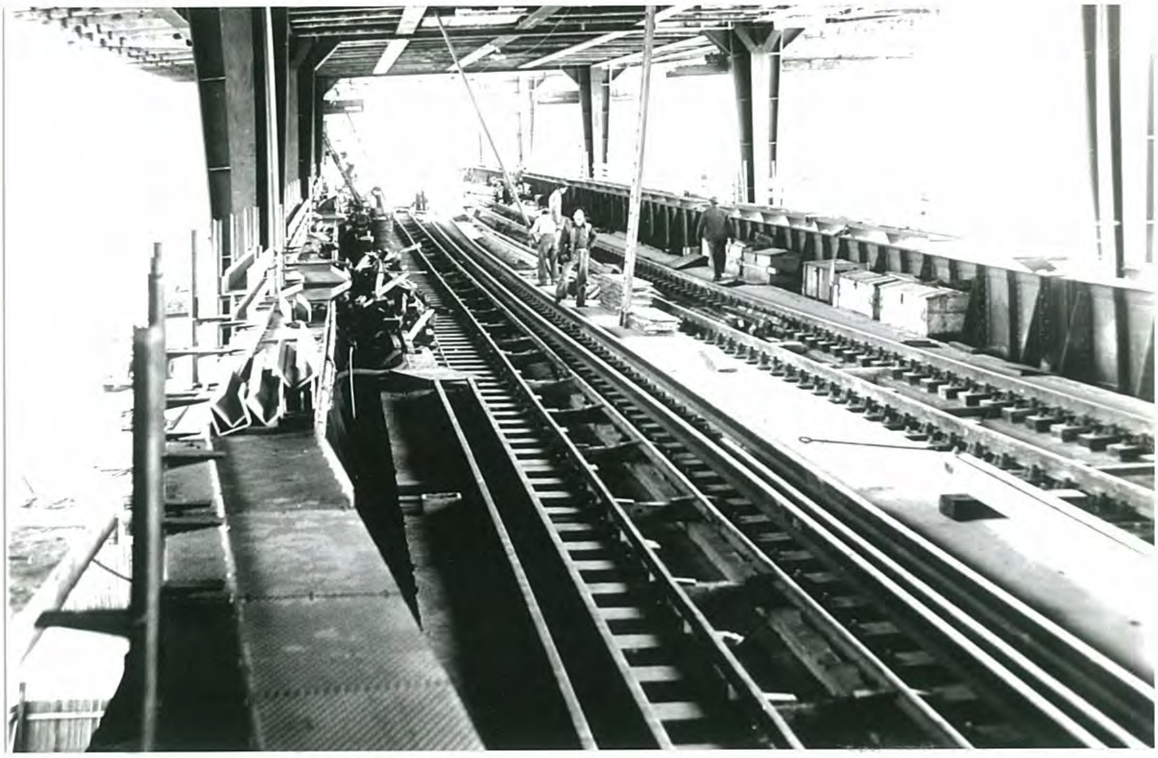


Photo location 7 - Railway approach viaduct at Circular Quay nearing completion late 1955, with Cahill Expressway above.

Photo location 7 - The official trial train at Circular Quay, December 1955.

Photo location 7 - Completion of the City Railway was formally acknowledged with the official opening train on 20 January 1956.

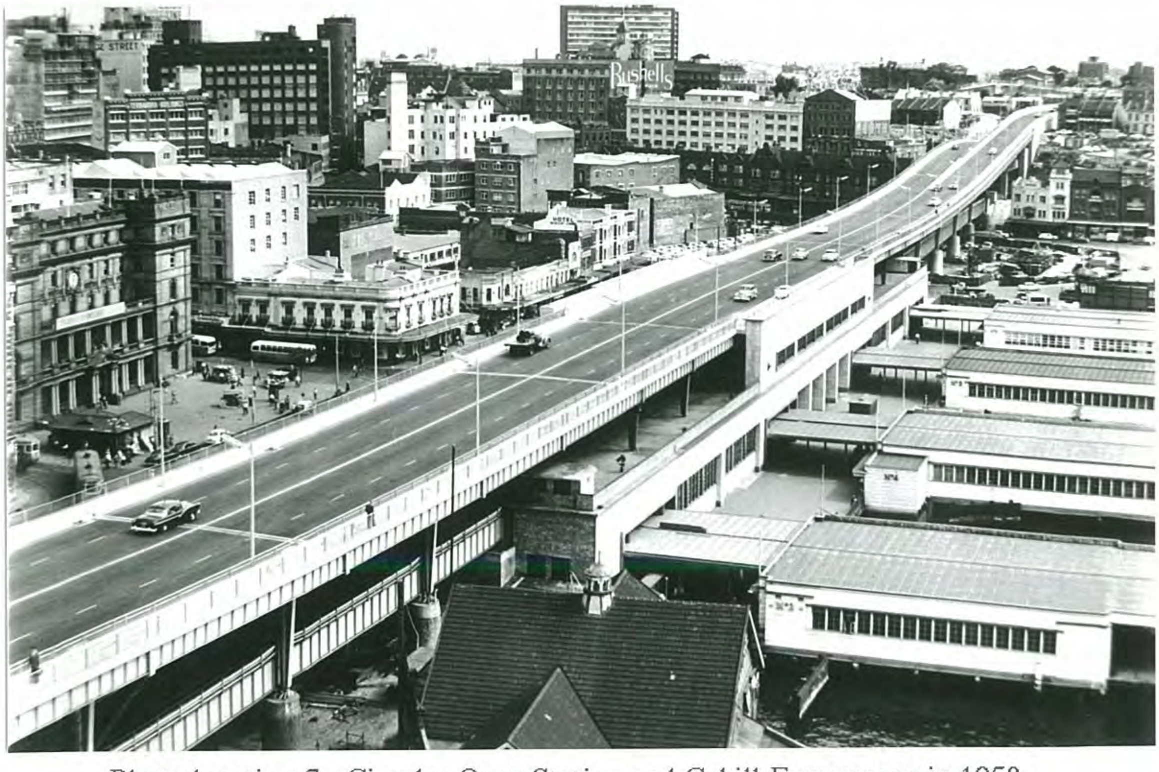


Photo location 7 - Circular Quay Station and Cahill Expressway in 1958.

Photo location 8 - The excavation for Wynyard Station. It is a dual line station, the lower level being the western side of the City Railway, and the upper level being for the North Shore Line as it heads north to the Sydney Harbour Bridge.

Photo location 8 - Wynyard Station is a 5-storey steel building buried below the restored Wynyard Square and York Street.

Photo location 8 - Wynyard Station was opened on 28 February 1932 for City Railway use and for the North Shore Line after the Harbour Bridge was opened on 19 March.

Photo location 9 - Town Hall Station was also on the western section of the City Railway and the North Shore Line. Traffic in George Street was diverted so a deep rectangular pit could be excavated starting in January 1930.

Photo location 9 - Sufficient excavation was done to erect the steel frame then a reinforced concrete roof slab was constructed in April 1930 so that George Street could be restored to its original layout.

Photo location 9 - This photograph of the restored George Street was taken after Town Hall Station had come into use in February 1932.

Photo location 9 - After George Street was restored in late 1931, excavation for Town Hall Station continued under cover, around the steel frame of the station building.

Photo location 10 - The link from Town Hall to Central slewed across under four blocks of city buildings. The two upper tunnels were too close to the foundations of the buildings for blasting. Hand excavation and extensive roofsupports were required starting as early as 1924.

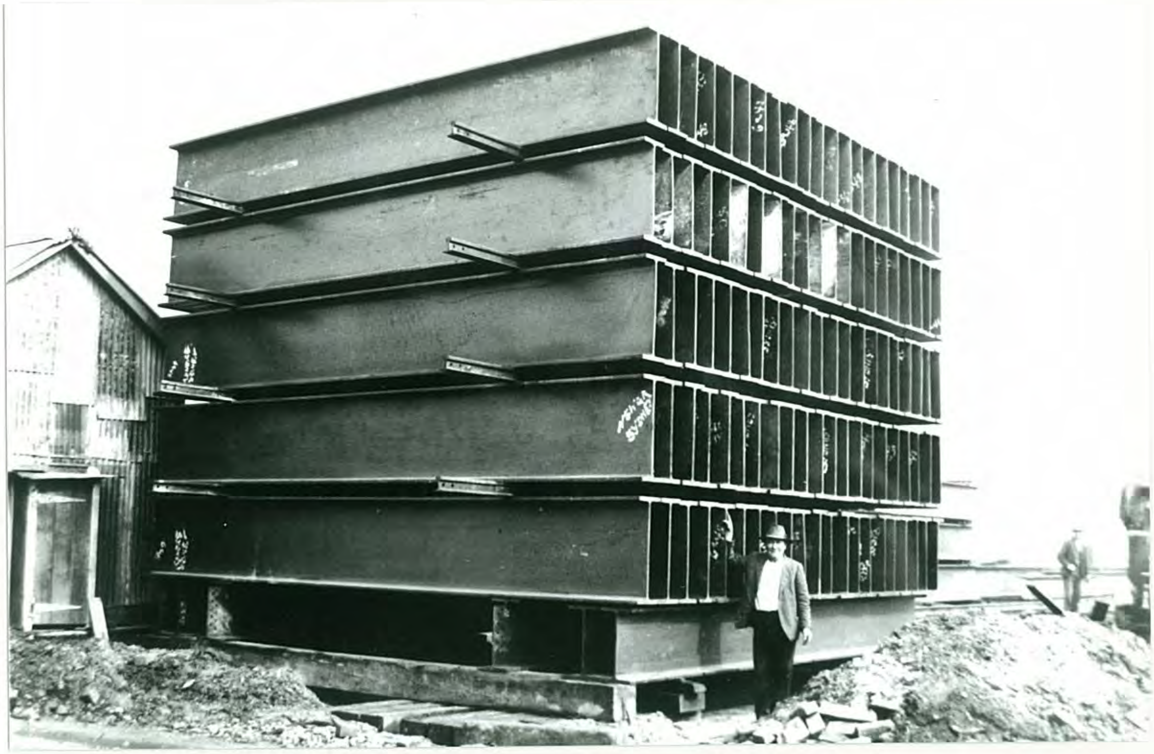


Photo location 10 - The Town Hall to Central section also required extensive underpinning of city building foundations using a large quantity of imported broad flange beams.

Photo location 10 - Typical scene in 1927 of the difficult site conditions for underpinning the foundations of city buildings. Here the tunnel is skew to the orientation of the foundation.

Photo location 10 - The underpinning work required constant variations to suit the great variety of building foundations encountered.

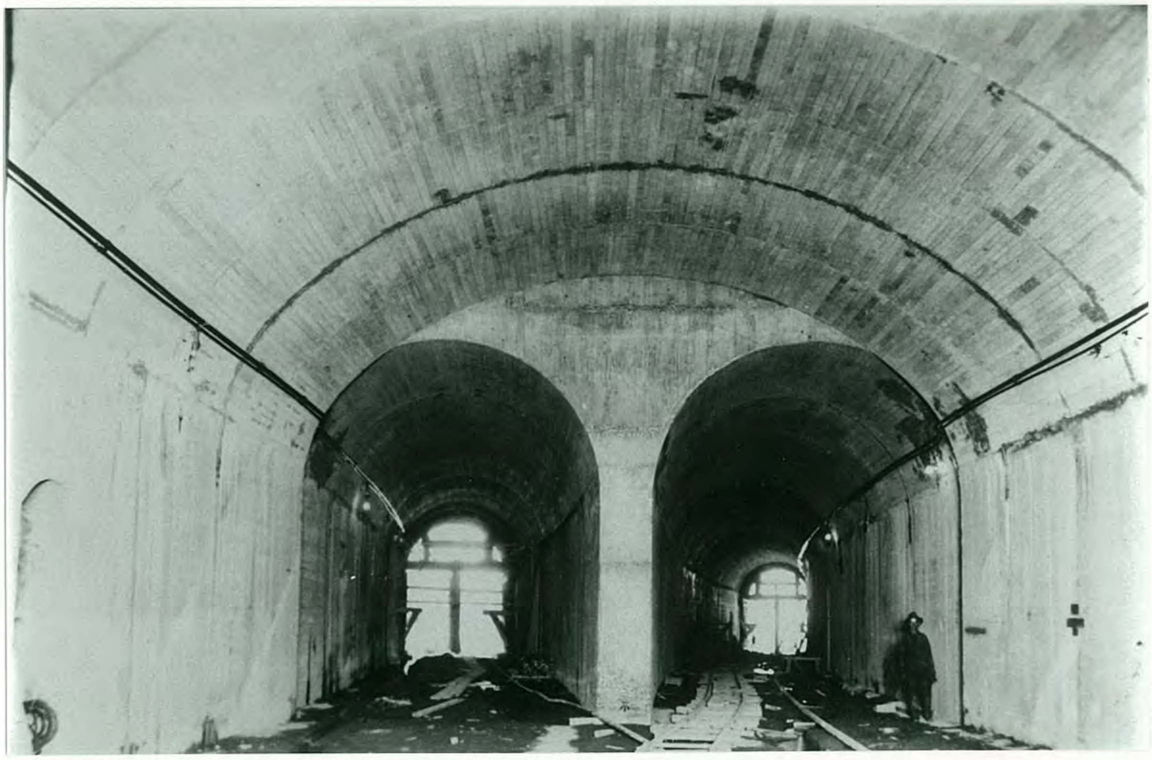


Photo location 10 - Eventually all the concrete-lined tunnels of the City Railway and the North Shore Line were completed during 1931.

Transactions

of

The Institution of Engineers, Australia.

Volume VIII.
1926.

Published by the Institution,
Macleay House,
16 College Street, Sydney,

faults have occurred since to test its effectiveness. The only serious failure experienced was similar to the above and due to the setting of an overload relay at Portland being too high and the amount of plant on the busbars at the time of the fault being insufficient to operate the relay. The high setting was given to allow the whole load of the station to be carried on a single circuit if necessary, but it has now been agreed to assume a minimum of two circuits to carry the maximum load and the settings of the overload relays have been reduced accordingly. A further improvement was made by connecting the overload relays as in Fig. 22, so that one relay of each group could be given a low setting for earth faults.

It may be said that the operation of the relays as a whole, and of the differential and busbar leakage relays in particular, has been very satisfactory.

In order to introduce other lines of defence in case of switch or relay failure, or of the almost impossible case of a phase to phase short circuit without leakage to earth in the substation or transformer, it has been decided to instal directional relays operated from current transformers on the bushings of the 33,000 volt bus section breaker. The impedance relay is the actual type selected and it will be connected so as to trip the multi-contact relay of the busbar leakage protection on the faulty side in case of a heavy transfer of current through the section breaker. If, for example, a line circuit breaker failed to clear a line fault, that half of the substation containing the faulty breaker would be cut out in about 0.75 seconds.

The author is indebted to Mr. F. W. H. Wheadon, A.M.I.E. Aust., Engineer and Manager of the Adelaide Electric Supply Company, Limited, for permission to publish the description of the Company's system.

[The paper is illustrated by Figs. 1-30 in the letterpress.]

THE RAILWAY SYSTEM,

Past, Present, and Projected, of the City of Sydney and its Suburbs.

JAMES FRASER, C.M.G. (*Member*).*
(*Read before Sydney Division*).

Historical Introduction.

The Railway System referred to in the title of this paper is in at least two respects unique—firstly, in that the terminus of the system has remained well outside the centre of the City since the first short length of railway was constructed, and, secondly, that the system has moved, and is moving at the present date, more trains, steam-hauled, per track per hour than any other System in the World similarly operated.

The various administrations, vested with the control of railway operation in the State of New South Wales, cannot be blamed for the first-named obstacle to the provision of adequate transport services for the ever-increasing number of patrons of the railway service. Practically every such administration, during a period of over 70 years, has represented the desirability of extending the railway system into or through the City so that passengers might be disembarked at a point, or at points, within comparatively easy reach of the business premises within the City wherein their daily avocations are pursued.

The second exceptional feature resulted from exactly the same cause as that which produced the first, viz., a hesitancy on the part of the people of the State as a whole to accept any of the schemes, submitted over a very long period of years, to provide such transport facilities as various Railway Managers thought both desirable and necessary, or to expend very large sums of money in the provision of track to enable maximum transport demands to be met with a reasonable margin of capacity.

This—the decision of the people as a whole—undoubtedly forced upon recent administrations an intensity of steam train movement unparalleled elsewhere, but, looked at from the present day point of view, it is quite clear that the non-acceptance of many of the earlier proposals for extension of railways to the City has been, on the whole, an advantage to all those chiefly interested in a satisfactory solution of the major passenger transport problems of to-day.

There is no need to describe, or even to refer to, each of the many schemes promoted for the better transport of Sydney's

*Chief Commissioner, N.S.W. Government Railways and Tramways.

suburban residents. It can be said, however, that had any one of these proposals, put forward before the year 1910, been actually completed, its value to-day would be negligible.

No individual at present engaged in a position of great responsibility in the transport industry would have the temerity to say that any scheme which could be prepared to-day would, by the date of its completion, solve for more than a year or two at most the problem of transporting the day habitants of any one of the World's great cities—even though facilities for swift, safe and convenient movement are greater now than formerly, and are constantly improving. Gauging the future from the past, and there is no other basis for a forecast, the demand for swift and convenient transport will continue to be greater than the power to afford it.

This may appear a somewhat pessimistic note to strike in a paper which will, some paragraphs hence, begin to have special reference to projected transport facilities for the area comprised within the boundaries of Greater Sydney. But the note appears to be justified by the conditions which obtain in the greater of the World's cities, where, in spite of the expenditure of sums of money, collossal in their magnitude, there is not the faintest hint that the passenger transport facilities are deemed to be satisfactory. Perhaps Australians will succeed to a greater extent than others, and, given the opportunity for a great effort, Australians have demonstrated possession of capacity in most matters at least equal to that of other nations. That a great passenger transport business has developed in and about this City, has been conducted by Australians under conditions that have not been continuously favorable, and has been operated with safety, a rather remarkable punctuality, and with no more inconvenience than attaches to other similar services elsewhere, will be disclosed by facts which will be now set out.

The suburban passenger business had no great proportions prior to the date when the administration of the New South Wales Railways was, in October, 1888, placed under the control of Mr. E. M. G. Eddy and his colleagues. Immediately after his taking office he deemed it necessary to widen the main Suburban line to Homebush from two to four lines, to duplicate the northern line from Strathfield to Hornsby, the Illawarra Line from Hurstville to Waterfall, and the southern line from Granville to Campbelltown. This work, completed early in 1892, gave to Mr. Eddy and his colleagues a total suburban track mileage of 251 miles 29 chains, over which, in the year of its completion, 15,000,000 passengers were transported by 39 engines and 188 suburban carriages. At the time the dupli-

cation work just mentioned was in hand, the then railway administration was pressing strongly (owing to the inadequacy of the old terminal station south of Devonshire Street) for the extension of the railway into the City, with a terminal station in Hyde Park, adjacent to St. James' Church. This and other somewhat similar proposals were all rejected and the whole of the passenger business terminated at the Devonshire Street Station—where 13 platform faces were available for trains—up to the year 1907. It is interesting to note here that, in the year 1905-1906, the last complete year of service given by the old terminal station, 25,000,000 passengers were handled at 13 platforms with relative track, and 19 years later 80,000,000 passengers were embarked and disembarked from 19 platforms —a 50 per cent increase in terminal accommodation with over 200 per cent. increase in business done—and to-day a slightly increased business is being conducted at 19 platform faces.

That that operation during recent years has been of a most intensive character is shown by the following comparative figures :—

Year.	Suburban Track Mileage.	Per cent. incr.	Engines operated.	Per cent. incr.	Cars in Service.	Per cent. incr.	Passengers carried.	Per cent. incr.
1893	251¼	—	39	—	188	—	16,400,000	—
1900	262¾	4.55	53	35.90	203	39.89	22,800,000	39.02
1907	273½	8.85	76	94.87	394	56.38	34,800,000	112.19
1914	314	24.97	145	271.79	786	318.08	72,700,000	343.29
1921	347¾	38.40	199	410.26	863	359.04	104,400,000	536.58
1925	389½	55.02	212	443.59	983	422.87	111,600,000	580.48

As long ago as 1909, when terminal and track facilities differed little from those which obtain to-day, it was considered that the transport problem had reached such an acute stage that it had become imperative to construct through the City a railway to be operated electrically, and to construct new and electrify the whole of the existing suburban lines. This, the view of the Chief Commissioner of the day, was confirmed by a Royal Commission appointed to consider the whole transport problem, and a recommendation was made by that Commission that the work be put in hand without delay. It is regretted that the action recommended was not given effect to then, as a good system, taken as a whole, could have been in operation many years ago at a cost very greatly below what a similar system will now cost. It is true that in the intervening years almost every detail of electric power production, transmission and utilization for transport work has been greatly developed, but the cost of bringing all such details up to present day standards would have been very small in comparison with the difference between total costs in, say, 1913-1914 and at the present time.

This is really a digression but it is a thought which must intrude itself when the financial aspect has to be considered.

To return to the year 1909, or thereabouts, the track and terminal facilities at that time were deemed to be fully loaded by the transport of 39,000,000 passengers in the year just preceding. The iron horse, though not in a senile condition, was thought to have passed the zenith of his power, while his younger rival—electricity—was developing with extraordinary rapidity. To some extent the thought was rational for though the steam locomotive had barely reached maximum development in some services, in others its use can no longer be justified from any point of view. Still, the steam locomotive has continued to move an ever-increasing business, though restricted to almost the same track and terminal as existed at the time of its condemnation as no longer efficient, and has made possible the transport of almost 112,000,000 suburban passengers during the year 1924-1925, an increase of over 187 per cent. from 1909. That is a remarkable record under the conditions, and one from which it could possibly be argued that steam still possesses such virility that there is not yet absolute need for change.

There is, however, on any given length of railway track a saturation point for any form of traction, and that point has now been definitely reached with steam services on existing suburban tracks. That the traffic carrying capacity of track is much greater under electric operation; that there is absolute need to land the day habitants of the city within a short distance of their ultimate destination; that a city railway is a foul thing operated by steam, and that a city railway electrically operated requires less track and can therefore be more cheaply constructed, are warrants enough for the urgent desire of the present railway administration to complete, as swiftly as possible, the electrification of all existing suburban lines and the construction of the city railway as approved.

Projected Transport Facilities.

The railway business and transport facilities of the past and present have been briefly touched upon, and it is possible dimly to visualise the future—dimly only—as the transport facilities of the future are dependent upon the will of the people as a whole to provide the funds necessary to enable plans to take material form in work completed.

Plans have been prepared, and have been stamped with Parliamentary approval, for something more than the nucleus of a great city and suburban electric railway scheme, and a considerable amount of work has already been carried out in connection with the first part of the scheme in question.

It has already been stated that, for a period of over 70 years, successive railway administrations have stressed the desirability of extending the railway into the city to make railway transport more perfect. It follows that during that great period of time a multiplicity of proposals has been submitted, considered, condemned, or pigeon-holed for future reference, but a design (momentarily final) was submitted by Mr. J. J. C. Bradfield,* in the year 1913, and approved by Parliament in the year 1915. This design, illustrated in Fig. 1, provides for the extension of six tracks from the present terminus into the city. Of these, four will be carried over Eddy Avenue, through Belmore Park, over Hay and Goulburn Streets, swinging from the latter point westerly towards George Street, near Bathurst Street, thence under the former street near Market Street, when again curving westerly they will be carried under York Street to Wynyard Square. From a station at this point two lines will be carried northerly to pass over the Harbour Bridge to North Sydney, and the other pair at a lower level will swing easterly towards Circular Quay and curving again east and south will pass under part of the Botanical Gardens, thence to Macquarie Street, and thence still southerly to the present terminus.

Within the City proper, passenger stations will be provided under the scheme approved at—

Town Hall	6 platforms;
Wynyard Square	6 platforms;
Circular Quay	2 platforms;
St. James	4 platforms;
Liverpool Street	2 platforms.

Suitable assembly platforms, means of ingress and egress, and all conveniences required for the public and the railway employees, will be provided at each station, and in such form as to function in their capacity for service with the train capacity of each station.

From the design point of view it may be necessary here to justify the present construction of six platforms at Town Hall and Wynyard Square stations. At the former, four platforms are obviously necessary for four main through tracks, and two others are being constructed now—it would be extremely difficult and costly at a later stage—to become part of an addition to the city railway system which will inevitably be required at a comparatively early date. At Wynyard Square, four platforms are required for a similar number of through tracks, and two for terminating tracks. A probable addition to the at present approved design for a city railway system having been mentioned

*Now Dr. J. J. C. Bradfield, M.I.E. Aust., Chief Engineer, Sydney Harbour Bridge and City Railway.

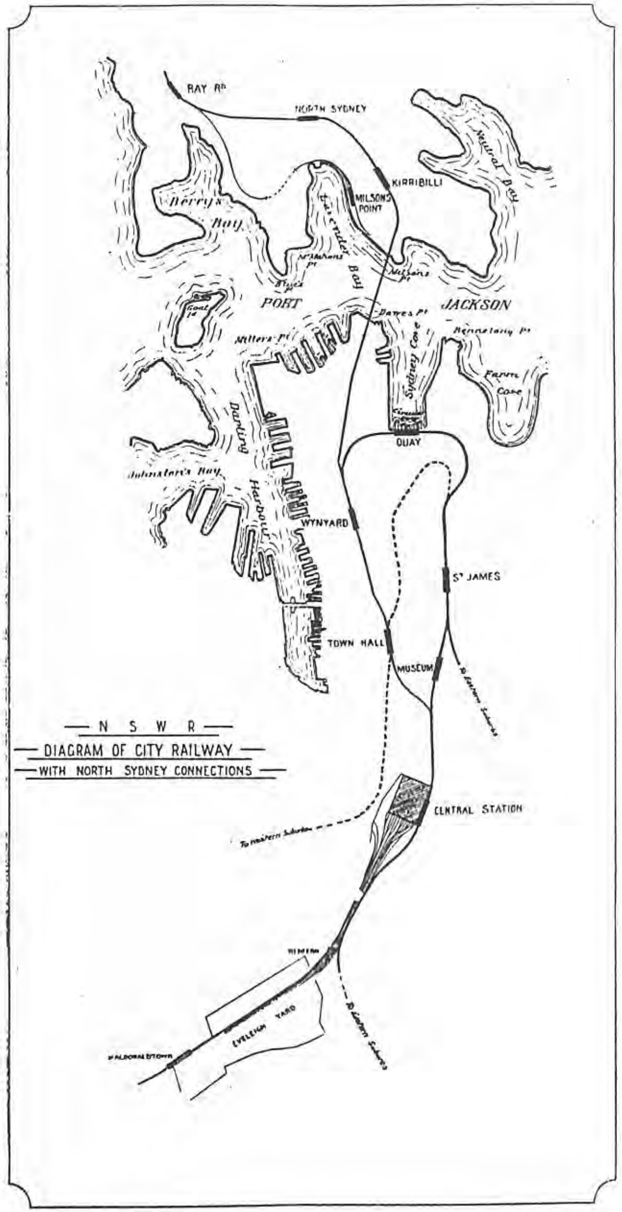


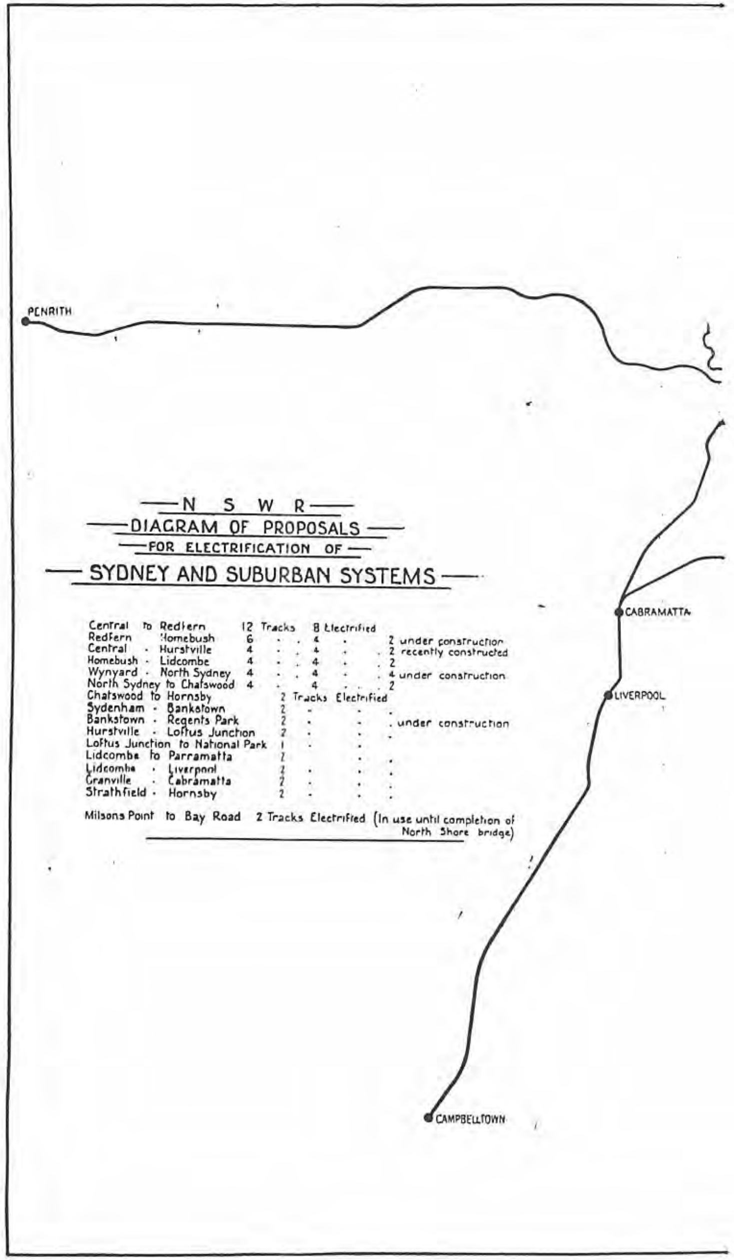
Fig. 1—Diagram of City Railway.

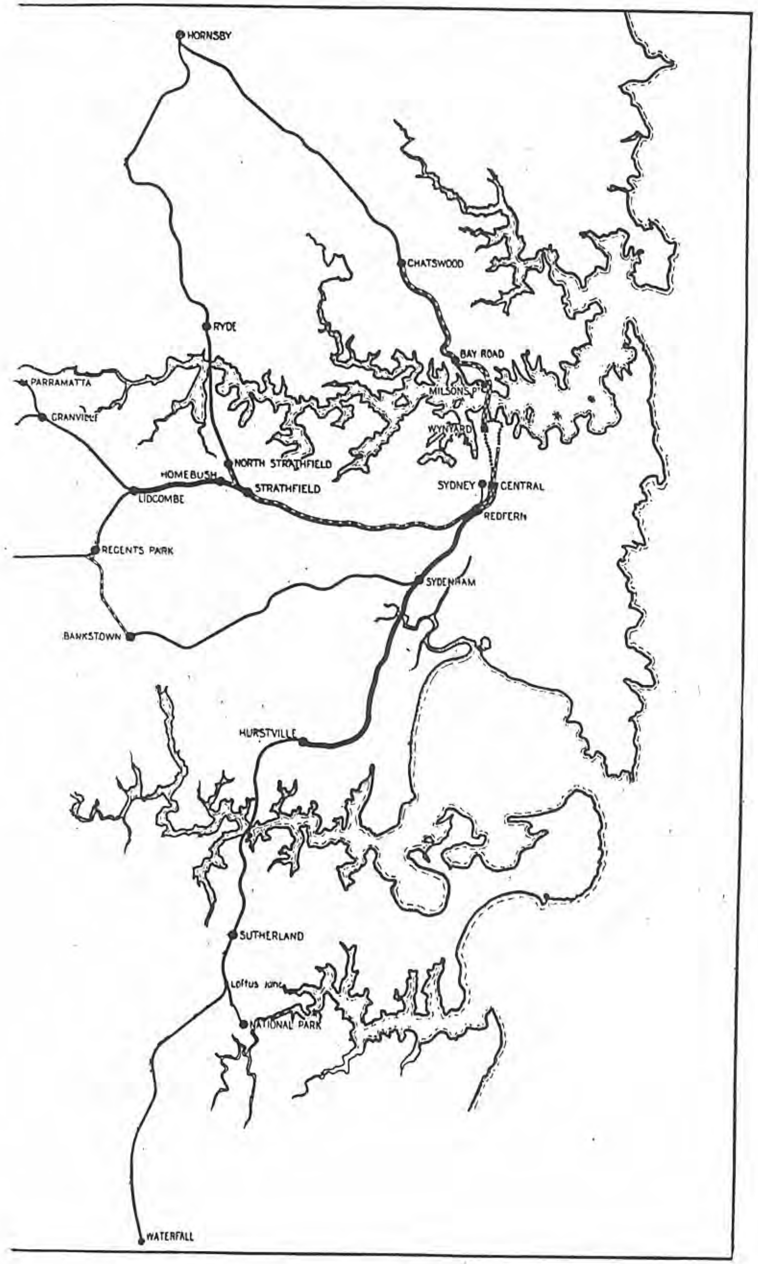
as inevitable, cannot be dropped with just that passing reference. Some indication of the need for addition to a great proposal hardly more than commenced must be furnished. Figures given in the earlier part of this paper show that passenger travel provided for by that system which this paper purports to describe in its broader details, increased by almost 600 per cent. in a period of 32 years, or at a compound ratio for the whole period of almost 5¼ per cent. per annum. The city and suburban population is increasing very rapidly (many critics say much too rapidly in relation to the population of the State as a whole), but the ratio of travel per head of population is not yet equal to that of many of the great cities of the World, and several densely populated areas presently dependent on less efficient transport services will, by extensions of suburban systems, add enormously to the patronage of the system as a whole and especially to that portion within the city area. Without referring in greater detail here to the probable daily passenger movement, but basing assertion merely upon the facts just stated, with one other, *viz.*, that the footpath capacity in the vicinity of the first stations brought into operation may prove inadequate for the pedestrian burden imposed, it would seem that additional city stations will inevitably be required at a comparatively early date.

Formerly it was intended that the Eastern Suburbs Railway should terminate at St. James' Station, and platform accommodation has been provided for that purpose, but as through track only possesses the attribute of maximum efficiency, and is therefore the more economical, it has been decided to depart from the original design, and, while using platforms constructed at St. James', provide for four through lines, two towards Circular Quay, as already mentioned, and the other pair by a shorter route through the city to two of the three lower-level platforms at Town Hall Station *via* two new stations to be located under O'Connell Street and under Pitt Street, between King and Market Streets. From Town Hall Station, the lower level lines just mentioned will be carried on by a route not yet definitely decided upon, but generally paralleling and to the north of Parramatta Road, to ultimately join up with the existing main Suburban lines near Homebush or Flemington. From these new trunk lines branches may be extended to the Western Suburbs, rapidly growing and not yet provided with adequate transport services.

Electrification of Existing Suburban Lines.

Whether a City Railway were constructed or not; whether a Sydney Harbour Bridge were to be only a beautiful dream,


PENRITH
CABRAMATTA
LIVERPOOL
CAMPBELLTOWN
N S W R
DIAGRAM OF PROPOSALS
FOR ELECTRIFICATION OF
SYDNEY AND SUBURBAN SYSTEMS
Central to Redfern 12 Tracks 8 Electrified
Redfern Homebush 6 . . 4 . 2 under construction
Central . Hurstville 4 . . 4 . . 2 recently constructed
Homebush . Lidcombe 4 . . 4 . . 2
Wynyard . North Sydney 4 . . 4 . . 4 under construction
North Sydney to Chatswood 4 . 4 . . . 2
Chatswood to Hornsby 2 Tracks Electrified
Sydenham . Bankstown 2 . . .
Bankstown . Regents Park 2 . . . under construction
Hurstville . Loftus Junction 2 . . .
Loftus Junction to National Park 1 . .
Lidcombe to Parramatta 2 . .
Lidcombe . Liverpool 2 . . .
Granville . Cabramatta 2 . . .
Strathfield . Hornsby 2 . . .
Milsons Point to Bay Road 2 Tracks Electrified (In use until completion of North Shore bridge)


HORNSBY
CHATSWOOD
RYDE
BAY ROAD
MILSONS PT
PARRAMATTA
GRANVILLE
WYNYARD
NORTH STRATHFIELD
HOMEBUSH
STRATHFIELD
LIDCOMBE
SYDNEY
CENTRAL
REDFERN
REGENTS PARK
SYDENHAM
BANKSTOWN
HURSTVILLE
SUTHERLAND
Loftus Junc
NATIONAL PARK
WATERFALL

electrification of the existing suburban lines would be a matter of immediate necessity, but it is of course much better to couple up north, south, east and west by lines radiating from a common centre. The present intention is to equip, for the introduction of electric traction, all those lines comprised in the suburban system, *viz.*, to Hornsby (north), Campbelltown (south), Penrith (west), and National Park (South Coast), together with the branches, Sydenham to Bankstown and Lidcombe to Cabramatta (See Fig. 2). Work in this connection was commenced on the Illawarra Line between Sydney and Waterfall on 1st March, 1923, and it may be said that, considering the magnitude of the work, excellent progress has been made.

Much that must be familiar to members has been written about the advantages of electrification of railways, but, in general, the assessment of economic value to any of the quoted advantages has been left as an interesting problem for the reader, or has been deemed to be confidential and available only to the management of the railway concerned. Each system is, however, an individual problem and must itself be critically examined and all factors affecting conditions under steam and electric operation given their correct relative values.

For reasons quoted in appropriate portions of this paper, four distinct major works are in progress at present within the Sydney Metropolitan area :—

(*a*) The provision of additional tracks to existing lines necessary to handle foreseen traffic of the immediate future, whether the service be operated by steam or electrically.

(*b*) The increase of clearances—enlargement of the structure gauge—to provide for the use of rolling stock of greater cross sections.

(*c*) The electrification of the existing lines.

(*d*) The construction of extensions to the existing lines through and around the City proper by the City Railway and the Sydney Harbour Bridge.

Costs where quoted in this paper or in subsequent papers to be read by Officers of the Railway Department must be allocated to their correct works and not so used as to burden incorrectly any of the separate works.

Of the above quoted major works (a) is necessitated by the growth of suburban population and need not be further dealt with at present ; (b) involves expenditure that will show a very large return on the investment by permitting an increase of the carrying capacity of all passenger trains per ton of weight and per foot of length, the latter providing a secondary advantage

by increasing the value of all platforms and sidings. Similar advantages will accrue in respect of goods trains by the decrease of the tare to load ratio and the increase of the effective nett tonnage carried per foot length of train ; (d) may be regarded as a separate work though the through connections to be provided will considerably increase the possible effective daily mileage of all rolling stock and hence will favourably affect the return on investment under other headings.

Many sound reasons could be quoted in support of the adopted policy to proceed concurrently with all four of the works enumerated above, but these are so obvious to engineers as not to warrant detailed mention.

Returning now to the electrification of the lines—certain advantages over steam traction are well known, others have been quoted, but it is also essential that the expenditure incurred shall return interest and this without augmenting revenue by increasing the average rate of fare.

To traverse the whole of the economics of the electrification of the Sydney Suburban system would be impossible in any paper, but some of the more important factors may be of interest.

The fact that the passenger transportation within the Greater Sydney area would quickly reach a density that would render electrical traction more economical than steam haulage, was established and accepted some years ago. Since that time all construction of locomotives and rolling stock has been arranged in such a way that, with the completion of electrification, no engines or carriages will be retired from service because of the altered method of traction. This is a most important feature economically for it frees the electrification debit of heavy sums that have had to be met by some organisations for the renewal of retired stock.

The average journey time for suburban trains during the peak hours of the day under the present steam system is almost exactly 35 minutes. Under electric traction this time will be reduced to 25 minutes. Considering conditions in the quite near future, one thousand cars will be necessary to handle the traffic electrically, but 1,400 would be needed under steam haulage. The present day value of the carriages and locomotives would be about £10,500,000, whereas the necessary electric stock will cost only £7,250,000 completely equipped, a difference of £3,250,000. Further, the accommodation and repairing plant necessary for housing, operating, and maintaining the steam service would, at present prices, cost quite £500,000 more than the necessary housing and accommodation for the electric

trains, giving a total difference so far as rolling stock is concerned of £3,750,000.

The capital investment for power houses, sub-stations, current reticulation, track bonding, etc., will amount to about £7,000,000 or a total excess—directly chargeable to electrification—of £3,250,000. The interest on this sum will be about £162,500 per annum, an amount far below the extra cost that would be necessary to operate a steam service, leaving out entirely the maintenance costs, which are considerably greater for a steam service.

Track capacity has been mentioned and it may be well to assess an approximate value for the better figure obtainable under electric traction. With steam operation the maximum number of trains that can be operated over each track per hour is about 20, whilst under electric traction more than 30 may be run, a clear gain of 50 per cent. The addition of two tracks between Redfern and Homebush is costing about £100,000 per mile of double track, which may be regarded as a fair valuation of any track in the inner suburban zone. Electrification therefore adds potentially £50,000 per mile of double track to the value of all track called upon to carry a traffic approximating the maximum density obtainable under steam conditions.

Neither the City Railway, the Sydney Harbour Bridge, nor any scheme of Suburban Railways can really be claimed to be the thought or the work of an individual. These works, when completed, will be the materialization of the best thoughts of a considerable number of able men; and, similarly, the electrification of existing lines has been designed by, and is being carried out by professional men of every branch of the Railway Department together with the Traffic officers, all working as a team to secure perfection in every detail.

Synchronization of dates for the completion of the various parts of the scheme so as to produce, at the smallest cost, a system operable in sections but with the work required for each section so co-ordinated that there will be no capital idle through the work of one branch slipping behind that of another, is the policy of the present railway administration. This policy has been so faithfully followed from the initiation of the work right up to date that it could almost be said that the last hammer blow was struck on the job of each of the branches on the 27th February to enable the first electric train to run between Hurstville and Sydney on the morning of 1st March, 1926.

There is scope for the writing of many papers intensely interesting to members of the engineering and allied professions in connection with the major details of that great composite work which will be the electric railway system of Greater Sydney, but even this, which is merely a preface to those later papers, would be very incomplete if it did not at least introduce those engineering features which— each functioning in its appropriate sphere— will be assembled into, perhaps, a more completely self-contained and perfect suburban transport system than exists elsewhere at the present date.

It is anticipated that a perfect feast of information will be supplied at later dates with regard to every important detail of the work now being and to be carried out; and one without attempting to make suggestions in a preface to a group of papers not yet read, may indicate those works which should be fully described so that there may be a permanent record of the details of each great achievement. The works in question include the following:—

(1) The civil engineering work associated with the electrification of the lines.
(2) The re-signalling of the existing lines.
(3) The provision of rolling-stock.
(4) The generation and reticulation of power.
(5) The construction of the City Railway and the Harbour Bridge to connect Sydney and North Sydney.

(1) *The Civil Engineering Work* necessary in connection with electrification of existing suburban lines entails something more than re-conditioning of track and re-construction of old, weak or in other respects inadequate structures, as the adoption of a more liberal gauge for rolling stock necessitates the widening of the spaces between tracks, and, as a corollary, the alteration or removal of platforms, bridges, station awnings, etc., to conform with a structure gauge in harmony with that adopted for rolling stock. Figures already given and others still to follow demonstrate the need for more track and new lines being provided where necessary. The Illawarra line, until recently a four-track line only as far as Sydenham, with double track beyond to Wollongong, has been quadruplicated to Hurstville. The main suburban line, now four tracks to Lidcombe, is being further widened by the provision of two additional tracks from Central Station to Homebush. These will momentarily be the only additional main tracks added to the system, but further new works have recently been completed, or are in hand. These include the provision of carriage sheds (with suitable bays for the carrying out of running repairs) at Punchbowl, Mortdale and Hornsby, and other suitable locations, extensive additions to the two Power Houses, the construction of the necessary sub-

stations, the construction of extensive workshops for the fitting of electrical equipment to rolling-stock and for the major repairs to rolling-stock, and the construction and erection of the necessary structures to carry the overhead conductor system and signals.

Permanent way and works having been briefly introduced; it will be left to Mr. R. L. Ranken, Engineer-in-Chief for Existing Lines, to describe the various works, major and minor, which it is his task to design and complete, and as Signalling, which comes next in order, will provide material for a very interesting separate paper, no more than a passing reference will be made to the mass of work properly coming under that heading.

(2) *Signalling and Interlocking*: In order to handle safely the very dense traffic that has developed in recent years in the Sydney Metropolitan area, the suburban lines have been equipped with the very best apparatus obtainable and much of the equipment now in use will continue to give service under electric traction. Extensive modifications and additions are necessary, however, in order to provide a system that will allow of the safe passage of the maximum practical number of trains per hour on each track in locations where ultimate capacity is desirable. Sections of the lines where D. C. track circuits had been installed have had to be converted to A. C. track circuits; signals have been increased in numbers and their locations varied; automatic train stops have had to be provided; the whole track has had to be bonded for the return traction current, and impedance bonds have had to be provided at all track circuit insulator points.

Much of the equipment and a number of the most important interlocking machines have been manufactured in the Department's own factories.

(3) *Rolling Stock*: This subject will be touched upon but briefly. It has already been stated that all new construction costs are reduced to the most moderate figures by increasing the carrying capacity of each track, and similarly the cost of rolling stock for passenger or other transport may also be reduced to the lowest level by the use of vehicles of the greatest practicable carrying capacity. This was the factor which caused the adoption (a few years ago) of a new rolling stock gauge, and to this latter all vehicles required for city and suburban services will be constructed. These cars measure 61 feet 6 in. in length 10 feet 6 in. in breadth, and 8 feet 9 in. in height. The widening from 9 feet 4 in. (old standard) to 10 feet 6 in. gives crosswise comfortable seating accommodation for five persons against four in the older vehicles. An increase of 25 per cent. is thus obtained at the trifling cost of increasing floor and roof widths by 14 inches only. The cars are carried on two four-wheel bogies of a purely Australian design, one of the original features being the electric welding (as against riveting) of the members of the bogie frame. Each train will consist of a number of units, variable at will to meet traffic demand, and the unit will be one motor coupled to one trailer car. Each motor car is equipped with two traction motors, each of 360 horse-power. While there are advocates for four motors, and four motors are used in many cases, the two-motor system possesses the advantage of much lower prime and maintenance costs, without, so far as it is practicable to estimate, any lesser efficiency. All cars will be well lighted electrically, with provision for emergency lighting from storage batteries, which is automatically switched on in the event of failure of line current.

(4) *Power*: This is a mighty word, and a man possessing the power to condense his description of all that is included in the production, conversion and distribution of that energy which will be used in the operation of the railway system herein briefly described, and still say all that is necessary to merit the term description, might well be envied by his fellows. Electric power production in this State had grown from infantile proportions to something approaching gigantic stature in a little over 25 years, and the Railway Commissioners may fairly claim to be the first real promoters of this form of energy. Starting with a small power house equipped with four horizontal compound engines, with generators of 850 kW. capacity—a house barely completed before it required reconstruction to admit of the introduction of more modern machines—later stages involving the removal of old and the introduction of more modern machines—made changes almost kaleidoscopic in character. Vertical compound engines, the first turbine, and others of the latter type, more powerful, more economical, pass swiftly across the screen. The passage across from the 850 kW. compound engine to the 7,500 kW. turbo-generator was short, and shorter still from the latter to what might be termed the first momentarily modern turbo-generator ordered in 1921. This, a 25-cycle 18,750 kW. machine, running 1,500 r.p.m., was partially constructed only when others still more modern (momentarily) were called for to meet power supply demands. Two of these latter, 50-cycle, 22,000 kW. turbo-alternators, running 1,500 r.p.m., have been in use now over twelve months, and another one is being erected. The leap in power concentrated in one unit has been, of necessity, accompanied by analogous.

changes in boiler and condenser construction, circulating water supply, as well as in switch boards (which are no longer switch-boards) and all those other minor appliances required in connection with control and determination of efficiency of each section of the plant. Buildings, too, designed to house properly this momentarily modern power plant have had to be erected and these (two only) are located at Ultimo and White Bay. The former has a total installed output capacity of 34,000 kW. and the latter of 105,750 kW.

These figures are, of course, correct only for to-day, as it is quite clear that further additions must be made in the immediate future, and when the areas already occupied will hold not even one more 50,000 or 75,000 kW. unit, which may then be deemed a reasonably modern type of machine, new ground must be broken and a new house erected elsewhere.

The power house, though it occupies the position of prime mover and is an almost silent giant in comparison with the comparatively feeble infant it evolved from, is a part only of the power scheme, as the current developed there must be transmitted, transformed and converted from alternating to direct current, at a potential of 1,500 volts carried by the overhead wire giving supply to the traction motors. Conversion is effected in suitably equipped sub-stations of which four are completed, viz., at Prince Alfred Park, Meek's Road, Hurstville and Sutherland, and others will be provided, in connection with the complete electrification of the system, at Belmore, St. Leonards, Gordon, Hornsby, Lewisham, Strathfield, Granville, Sefton Junction, Cabravale, Eastwood, Wynyard Square, Town Hall and Illawarra Junction.

The equipment of these substations will not vary greatly one from another, and will generally comprise standard rotary converter units of the self-synchronising pony motor started design. In the Prince Alfred sub-station, the rotary converter units are rated at 4,500 kW. each, while the larger sub-stations on the inner suburban zone are equipped with rotary converter units rated at 3,000 kW.; the sub-stations on the outer zone are equipped with 1,500 kW. rotary converters.

The sub-station at Prince Alfred Park, and all other sub-stations in the city proper, will be supplied at 6,600 volts, 25 cycles. The sub-stations on the inner suburban zone will be supplied at 11,000 volts, 50 cycles, and the stations on the outer suburban zone will be supplied at 33,000 volts, 50 cycles, the transformation from 11,000 to 33,000 volts taking place at the inner suburban zone sub-stations. In the case of the 25-cycle sub-stations, the conversion is effected from alternating current

to the 1,500 volt D.C. supply by a single rotary converter, while in the 50-cycle sub-stations, the conversion is effected by connecting two rotary converters in series.

(5) *The Sydney Harbour Bridge* does not merely provide a road connection between Sydney and North Sydney as was the intention in the remote past, but is essentially a part, and a very important part, of the City and Suburban Railway scheme. Two-thirds of its cost will be debited to railway capital, and it must become revenue producing on a grand scale to provide for interest and maintenance costs.

The City Railway has already been introduced and a full description of this and the Sydney Harbour Bridge may safely be left to Dr. J. J. C. Bradfield and his principal assistants.

Financial Considerations.

Having dealt at some length with the work which is being undertaken, it becomes necessary to count the cost, and if possible to show that financial results may justify the expenditure.

It is estimated that the total cost of the work at present authorised will be :—

Sydney Harbour Bridge ; two-thirds debitable to Railway Capital	£4,000,000
City Railway	£6,950,000
Electrification and Widening of Suburban Lines, immediately necessary	£8,981,000
New Rolling Stock	£5,805,000
	£25,736,000

Will the additional business accruing as a result of the expenditure be of such magnitude as to cover the working expenses involved, and leave a sufficient margin to provide interest on the very greatly increased capital debit ? It is felt that the answer can be in the affirmative, as the following figures will demonstrate :—

For the purpose of estimating the probable number of passengers seeking rail transport in the year 1930-31—when it is anticipated that the City Railway, the Harbour Bridge, and Electrification of existing Suburban Lines will have been completed —it would not be correct to base such an estimate on the average increase in travel during the period between 1914 and

the present date, as in the first four years of that period the Great World War caused stagnation here, though to a less extent than in some other places, and in the later years of the period mentioned there has been loss of business to the Railways by competition of other transport services. The actual increase in passengers carried from 1914 to 1925, as shown by the table presented earlier in this paper, was 38,900,000, or nearly 54%, which represents rather less than a compound ratio of 4% per annum. In view, however, of the fact that from 1907 to 1914 the total increase in passenger movement was about 109%, or over 11% compound ratio per annum, an estimate of the probable increase during the next six years at a rate of 9% per annum compounded should not be regarded as unduly optimistic. It may be remembered that the present Central Station was opened for traffic in the year 1907, and the greatly improved facilities given by that Station in conjunction with an excellent tramway service to the City were prime factors in the great increase in business which resulted.

A broken service, however good, cannot achieve such results as may be anticipated from a more perfect through service, and the estimate of a total increase of 66% for the period 1925-31—now to be taken in estimating financial results—is rather pessimistic than optimistic. Taking this figure, however, the suburban passengers carried in the year 1930-31 will total 185,256,000 but of these about 2-5ths will be picked up or alight at stations short of the City itself, while approximately 3-5ths will make complete journeys to the new city stations. The latter number will, therefore, total about 111,000,000 passenger journeys per annum, and the revenue for that travel, based on present mileage fares, should reach a sum of £800,000 per annum.

The City Railway and the Harbour Bridge are expected to cost £10,950,000 and the interest upon this expenditure at 5% per annum will total £547,500, which, deducted from the revenue derived from this new construction, leaves a margin of £252,500 to cover the additional working expenses involved, and it may be confidently stated that the sum mentioned will be more than sufficient for that purpose.

Turning next to that expenditure which is being incurred in electrification outside the City, the widening of lines, and provision of new rolling stock: these works, as shown, will entail the expenditure of new capital amounting to £14,785,000 on which an interest bill of £739,250 per annum will accrue, and the point now to be discussed is whether the revenue to be derived from the additional business expected will cover that

quite considerable interest bill and the working expenditure involved.

The average amount received per passenger journey on the Suburban System during the last financial year was 4.58d., and assuming that a similar sum is received for each of the additional 73,656,000 passenger journeys anticipated in 1930-31, the additional revenue received will amount to £1,405,602, so that, after providing for interest, there will remain a sum of £666,352 to cover the working expenses in connection with the additional transport services involved. As it is not likely that the new working expenditure will exceed 33% of the new revenue, there should be a margin surplus in this business of almost £200,000 per annum.

Need more be said? The great works in progress will markedly improve the major passenger transport service by reducing the time spent in daily travel; by more frequent service of a superior quality to that now possible; and by facilitating transit as between widely separated suburbs. It may also be confidently stated that the provision of these great arteries within the City of Sydney, which will ultimately enable 800,000,000 people per annum to be carried into and through the City, should so greatly relieve the carriage-way area of city streets as to eliminate for some time any fears of grave street congestion. "Great expectations" it may be said, but is there, on the closest scrutiny of the facts submitted, any reason to doubt that all anticipations will be realised and this great combination of works, the materialisation of brain emanations of Australia's great engineers, prove to be equal, if not superior, to any solution of a great traffic problem effected elsewhere, and that without adding to, but rather, reducing, the expenditure for travel incurred by its patrons?

Finally, in "measuring up" the total value of these great works to the people for whose use they are being completed, it surely is reasonable to place a value upon the time that will be saved by the millions of passengers who will benefit by the improved transport afforded. In the year 1930-31 the time saving to the suburban travelling public, as a result of acceleration of services, will amount to no less than 20,000,000 hours, or a time value of no less than £1,000,000 per annum, assessing each hour at the low value of 1/-. Capitalized, this saving equals nearly four-fifths of the total cost of all the works, and there must be added to this the appreciation of land and property values, probably many times in excess of the above figures.

Conclusion.

It may be permitted in the closing words of this paper to introduce a personal note and to say that the author feels that those who have patiently followed its presentation will appreciate his desire to extend to those most greatly responsible for the successful completion of the work, full credit for the results achieved and in this connection desires to mention the names of his colleagues Messrs. O. W. Brain and A. D. J. Forster; Mr. R. L. Ranken, Engineer-in-Chief for Existing Lines; Mr. C. B. Byles, Signal Engineer; Mr. E. E. Lucy, Chief Mechanical Engineer and his Chief Assistant, Mr. W. A. G. Douglas; Mr. W. H. Myers, Chief Electrical Engineer; Dr. J. J. C. Bradfield, Chief Engineer for the Sydney Harbour Bridge and City Railway; Mr. C. A. Hodgson, Chief Traffic Manager; and Bill Farrow, an old friend who has done notable work as Supervisor of the very difficult task entailed in carrying out the construction through the City of Sydney.

[The paper is illustrated by 2 Figs. in the letterpress].

ELECTRIFICATION OF SYDNEY AND SUBURBAN RAILWAYS.

I.—TRACK AND CONSTRUCTION WORK.

BY ROBERT LIMOND RANKEN (*Member*).*

(*Read before Sydney Division.*)

Introduction.

In endeavouring to explain as lucidly as possible, and make the description of the work sufficiently interesting and attractive, a knowledge of the several organisations of the service and how they combine in the carrying out of the various changes and operations should be helpful.

Having decided on the section to be converted from steam to electric traction, estimates of cost are prepared from accurate survey and design to suit the various Branches. Traffic requirements call for the arrangement of track alterations to be so designed as to interfere as little as possible with the existing tabled train operations, also the provision of commodious car sheds for train stabling and inspection. Signalling details are so tied up with the track conditions as to render imperative a very careful co-operation between that and the Permanent Way Branch, and the Electrical Engineer, who is responsible for the proper lay-out and maintenance of the overhead wiring and also the location of the high tension main distribution, requires that his arrangements fit in with the general design.

The Locomotive Branch calls for the provision of manufacturing buildings, inspection and repair shops, for the proper maintenance of the multiple-unit and other coaches required for the service. Later on, electric locomotives required for heavy mountain and goods operation will also receive attention in these shops.

Inspection sheds are also required as annexes to the car sheds already referred to as a traffic establishment, where machines are installed to deal with minor repairs.

* Engineer-in-Chief for Existing Lines, N.S.W Government Railways.

believed that only the highest grade of equipment has been installed, is sufficient indication of the confidence reposed in such firms' ability to meet the exacting requirements of the work. One must also acknowledge the able assistance rendered by local representatives of the contractors in the erection of the larger power plant.

However, appreciative though one may be in this connection, it must also be apparent that the design and supervision of the work as a whole falls most heavily on the staff of the Electrical Branch of the Railway Commissioners. The following verbatim copy of the concluding paragraph of the paper (beforementioned), by Mr. O. W. Brain, serves precisely to illustrate the views of the present Head of the branch :—

" It is hoped that the absence of any acknowledgment, either in connection with this paper, or the design of the power-house, will not appear ungraceful. Members quite realise that the work of the Department is done by the officers ; with regard to whose services, while there are both cause and inclination to speak in the highest terms, the expression of my views might not appear in place here."

One must again gratefully acknowledge the assistance rendered by the Chief Electrical Engineer, (Mr. H. P. Colwell), and staff of the Victorian Railways in several important features of the designs. The close collaboration existing between the two departments concerned is, of course, of considerable mutual benefit.

[The paper is illustrated by 22 Figs. in the letterpress, and Appendices I-VI are included.]

ELECTRIFICATION OF SYDNEY AND SUBURBAN RAILWAYS.

V.—THE CITY RAILWAY.

By John Job Crew Bradfield, D.Sc. Eng., M.E., (*Member*).*

(*Read before Sydney Division*).

1. *Introduction.*

The railway within the confines of the City proper will be, so to speak, the heart of a far-flung system of electric railways serving the northern, eastern, southern and western suburbs. Within the Metropolitan area, the existing steam railways are being electrified and a system of new electric railways has been devised to serve the suburbs not yet in railway communication with the City.

The Metropolitan area covers 133,940 acres ; with an unimproved capital value of £116,325,353 ; a population of 1,103,770 or 8.24 persons per acre, occupying 220,720 houses.

Central station, the present dead-end terminal of the New South Wales railway system, aggregating on 30th June, 1925, some 7,524 miles of standard gauge track, including sidings and crossings, is situated at the southern end of the business area, a peninsula $2\frac{1}{4}$ miles long by $\frac{1}{2}$ mile wide. Two hundred and fifty thousand passengers per day travel between the station and the city by street cars, by motor 'buses or walk. During the peak hour of the homeward evening traffic, over 40,000 people arrive at Central station to be taken to their destination by train ; whilst during this hour more tramway accommodation on the streets is well nigh impossible.

On the northern side of Sydney Harbour, Milson's Point is the terminal railway station where train and tram disembark their teeming thousands, to continue their journey across

*Chief Engineer, Metropolitan Railway Construction and Sydney Harbour Bridge.

the water by ferries plying at 6-minute intervals: similarly, from the hinterland of Manly, from Athol, Mosman, Cremorne, Neutral Bay, McMahon's Point, from Balmain and Watson's Bay, trams carry many thousand passengers daily to the water's edge to be conveyed to and from the City by ferries.

2. *Description of Route.*

In designing the system, the decision had to be made whether the railways in the City proper and the immediate suburbs were to be wholly underground, deep down, served by lifts and escalators, or whether, as far as possible, they should be located just below the surface and in the open air where practicable. The Harbour crossing was largely the deciding factor—was it to be a bridge or tunnel linking Sydney with North Sydney? If bridge, the location of the Metropolitan Railways would be for the most part open air; if tunnel, the location would be wholly underground. In 1913, the Parliamentary Standing Committee on Public Works adopted the high level bridge scheme originated by the author for connecting Sydney with North Sydney as against the subways recommended by the Royal Commission in 1909. In 1914, the author was sent by the then Minister for Works, the Honourable Arthur Griffith, to visit the Underground Railways throughout the World, and report on Sydney's transit problems. In 1914, the author submitted a comprehensive report of the Proposed Electric Railways for the City of Sydney, recommending a high level location which was adopted by Parliament instead of the low level location recommended by the Royal Commission on the Improvement of the City and its Suburbs.

Necessarily, traffic requirements have increased since 1914; motor 'buses are seriously competing with the tramways which were then almost inadequate to cater for the passenger traffic, and provision has been made so that an inner loop railway can be constructed within the City at some future date, and interchange passengers at some of the stations now being constructed.

Fig. 1 shows the Metropolitan area from the Blue Mountains to the coast; the existing railways are shown in black, those within the suburban area from the Hawkesbury River, Penrith, Campbelltown, Waterfall, etc., will eventually be electrified, whilst the new electric railways proposed or under construction are shown by white lines; the City Railway and connecting railways *via* the Bridge to Bay Road station, the proposed railway to Mosman, Manly and Narrabeen, the St. Leonards-Eastwood

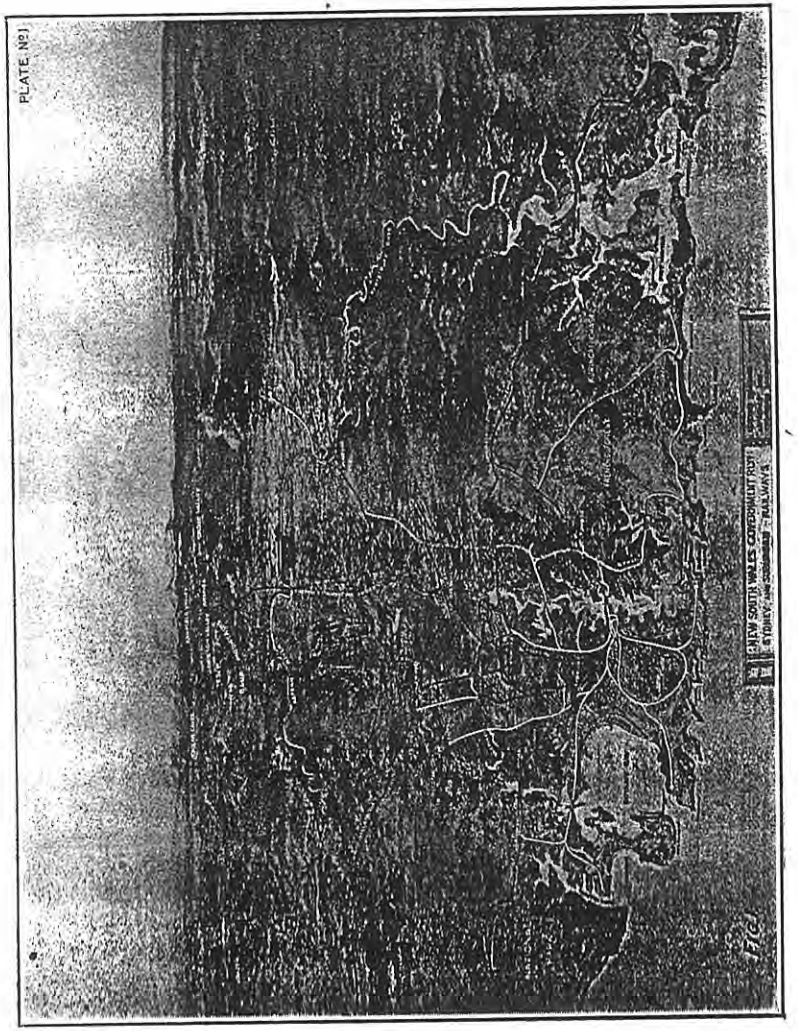


FIG. 1.

Railway, the Gordon to Narrabeen, the railways to the Eastern Suburbs, the Tempe to East Hills railway, a new railway midway between the existing railway to Strathfield and the Harbour, connecting with the Main Line at North Strathfield and with the St. Leonards-Eastwood railway with spur line extension to serve Balmain, Haberfield and Ryde.

Fig. 2 shows the City Railway as now being constructed; also the inner loop and the cross City tracks from North Sydney

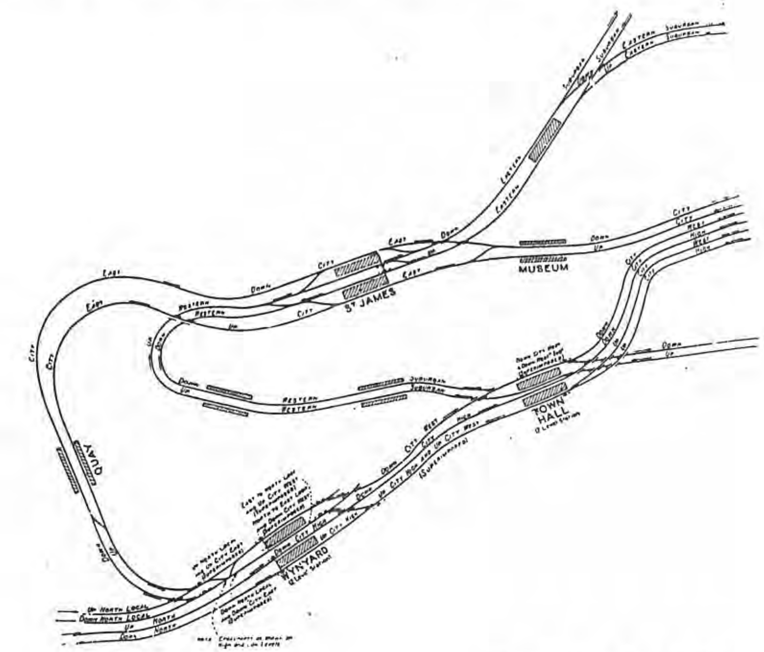


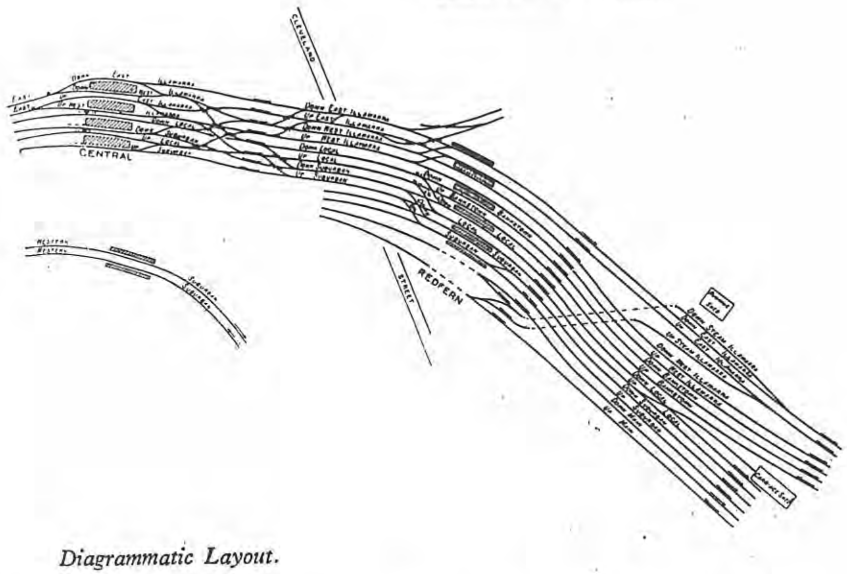
Fig. 2—The City Railway—

to the southern suburbs. The City Railway will junction with the existing railways at Wells Street, Redfern, eight tracks continue as the City Railway, whilst four tracks will run to the present Central terminal to handle the country steam trains; on the eastern side of Central station will be a new open-air electric station having its passenger and baggage facilities inter-connected with the existing terminal. Between Redfern and Central station will be a system of fly-overs, which are now being constructed, for routing the traffic on the City Railway and to

bring the Up and Down tracks in pairs to opposite sides of island platforms—at Central station where there will be four island platforms, each platform being served wholly by either down or up trains.

After leaving Central station, the Up East Illawarra and Up West Illawarra connect to form the Up City East; and on the northern side of Central Station the Down City East bifurcates to form the Down East Illawarra and Down West Illawarra. The four tracks from Strath-

THE CITY RAILWAY
DIAGRAMMATIC LAYOUT



Diagrammatic Layout.

field, together with the Up and Down City East—six tracks in all—continue City-wards, along Belmore Park across Hay Street and Campbell Street and run underground in the block of property bounded by Elizabeth, Campbell, Castlereagh and Goulburn Streets. Four tracks then diverge and pass around the western side of the City to a station under George Street in front of St. Andrew's Cathedral and the Town Hall, and thence under George Street to Wynyard Station, a two-level station under Wynyard Square Park, at the junction of the Bridge railways with the City Railway. From the

upper level, two of the City Railway tracks pass across the Bridge, whilst the other two tracks at the lower level lead to Circular Quay where there will be a combined passenger and ferry station and thence the railway continues along the eastern side of the City, becoming the Up and Down City East, with stations, St. James' at the northern end of Hyde Park and Museum near Liverpool Street.

Four lines of railway will cross the bridge, two of these tracks, after leaving Wynyard Station, will become the North to East and East to North Loops serving a station located between Pitt and Castlereagh Streets near Market Street, a station near Wentworth Avenue, another at Central and thence through the easternmost arch of the Cleveland Street Bridge to East Hills connecting with the Eastern Suburbs Railway and the East Illawarra Railway.

Traffic from the eastern suburbs will run through St. James station on the City Railway now being constructed and thence by the inner loop to a station under O'Connell Street between Bent Street and Hunter Street, to a second station under Pitt Street between King Street and Market Street, connecting thence with the City Railway at Town Hall Station, thence under George Street to a station at Railway Square on the western side of Central station, and thence along George Street West with a station near the University gates, and will connect with the Main Northern Line at North Strathfield.

The City Railway and the future extensions outlined have been so located that all crossings of tracks, carrying traffic either in the same or the opposite direction will be by means of fly-over crossings, thus ensuring the maximum possible train capacity for the tracks, with absolute safety. When the whole scheme is complete, passengers from the eastern, southern and western suburbs can reach six stations within the City proper without changing trains; whilst passengers from the northern suburbs can reach at least three city stations without changing trains. Easy interchange is provided at St. James, Wynyard and Town Hall stations, and with an interchange at one of these stations passengers from any suburb can reach any other suburb; in most cases even this one interchange for intersuburban passengers will be unnecessary.

To route the trains as required and to provide the greatest possible flexibility and safety, a system of fly-overs was designed between Cleveland Street bridge and Central station, whereby the four Up tracks become high level tracks, and the four Down tracks low level tracks, so that it is possible to divert a train from

the Up East Illawarra to the Up West Illawarra; from the Up West Illawarra to the Up Local and from the Up Local to the Up Suburban with the corresponding interchange from the Up Suburban, Up Local, Up West Illawarra to the Up East Illawarra without crossing the trains leaving Central station for the suburbs, so obviating the vexatious delays which now occur when a train requiring to enter Central Station is held up for a train scheduled to leave that station. Electric trains leaving Central Station will have the same flexibility of movement and the train capacity of the City Railway will be increased by at least 30 per cent. The distance between the Cleveland Street bridge and the southern end of Central station is 2,242 feet and in this distance it was just possible to locate the fly-overs; the four Up tracks arrive in pairs at two island platforms whilst the four down tracks similarly depart from two island platforms, facilitating the interchange of passengers.

Fig. 8 shows this comprehensive system of fly-overs, the largest in the world, there being 14 fly-overs and two level crossings, these latter accommodating trains in the same direction. When the tracks reach saturation point it will be possible to transfer the trains from any one track to any other track in the same direction without materially slowing down the running.

On the City Railway now being constructed, there are six stations, open air at Central and the Quay, and underground at Museum near Liverpool Street, St. James, Wynyard and Town Hall.

3. *Location, Grades and Curves.*

As the State owns the railways and tramways it has been possible to devise a scheme enabling trains to be run between the suburbs and outlying districts and the business area of the City without changing passengers from one railway system to another as is usually necessary in large cities where the transit systems are controlled by separate authorities, or of changing from train or ferry to the tramway system as at present in Sydney.

Contemplating the problems involved in planning a rapid transit system, many questions of fundamental importance arise, and before describing the present scheme, consideration will be given to the main factors governing the selection of the most suitable route. Certain districts have to be served and some situations are far more desirable for station location than others. In an endeavour to limit the cost of resumptions to a reasonable figure, it is advisable to follow the street lines wherever possible, while the cost of permanent underpinning makes

it expedient to avoid heavy buildings where practicable. There are two methods of location, either a high level or a low level route. In the high level project, advantage is taken of the natural contours of the city by locating the line partly underground and partly on viaduct, while with a low level scheme, the tracks would be placed at such a depth that the surface contours had no bearing on the location. An example of this method of location may be cited in the Central London Underground Railway, constructed from 60 to nearly 200 feet below the surface.

The advantages of the high level location for Sydney greatly exceed those which would eventuate from a low level location. With the high level location the interference with property above ground is greater, but a considerable amount of permanent underpinning can be avoided, and when property is resumed the land can be sold at an enhanced value. As a rule, these considerations balance the greater cost of resumptions.

For a low level location, the continued effect of the grades is worse than for a high level location; the ruling grade is the same but long runs on maximum grade are necessitated. Long down grades, with consequent increases in the braking distance of trains, necessitate longer block sections and thus, by increasing the allowable headway between trains reduce the capacity of the system.

All things considered, the high level scheme is the better solution to the problem from the construction point of view, especially so in respect to the builidng of underground stations at sites such as Circular Quay or Central station.

From the point of view of ventilation, a low level scheme in a climate as warm as that of Sydney would, with even elaborate ventilating equipment, cause a considerable amount of discomfort to passengers. With the high level scheme, having tunnel openings at Circular Quay and Goulburn Street and with easy communication with the outside air at all stations, no discomfort should be felt, even in the absence of any artificial ventilation.

Parliament approved of the high level location, the railway being out of ground from Wells Street, Redfern, to Goulburn Street and from Harrington Street across the Quay to Macquarie Street; the eastern tracks from Goulburn Street to Macquarie Street and the western tracks from Goulburn Street to Harrington Street being underground. In locating the underground portions, the streets were followed as far as practicable so as to limit the cost of resumptions and the cost of underpinning.

The basis of the detailed design of the City Railway is a traverse following the approximate route. This traverse has angle or intermediate stations some 300 feet apart, constituting a loop or closed traverse, while the error of closure was distributed so as to make the adjusted survey close mathematically for the purpose of co-ordination.

The azimuth of the survey has been taken from the old trigonometrical survey of the City of Sydney and the co-ordinate value of all stations computed, by taking the trigonometrical station at the Observatory as an origin and treating the area covered by the survey as a plane.

Considerable use has been made of the old detail surveys, which have been tied into the present railway traverse while practically all the new detail surveys required have been based directly on them.

The station sites on the City Railway were first determined on; the limiting grades were fixed as 1 in 30 with, and 1 in 40 against the load. The sharpest curve is 500 feet radius but generally the curves are 20 chains radius. The maximum permissible speed on curves is $1.1\sqrt{R}$ miles per hour, where R = radius in feet, so on a curve of 500 feet radius the permissible speed will be between 24 and 25 miles per hour.

All curves less than 20 chains radius are transitioned with a parabolic curve of the form $y = mx^3$ which has the effect of gradually increasing the radius. The minimum length of transition is $\frac{85000}{R}$, but longer lengths are used if possible. Transition may be reversed directly and the minimum reversing length on large curves not transitioned is obtained by the sum of half the two minimum transitions to be used on such curves. The grades are connected by vertical curves of simple parabolic type $y = mx^2$.

The minimum length of ease is such that the rate of change of grade does nor exceed 1% per chain for sag, and $1\frac{1}{2}$% per chain for summits, longer eases being used where feasible.

The superelevation is taken as $E = \frac{4S^2}{R}$, where S = speed in miles per hour, R = radius in feet, E not to exceed $4\frac{1}{2}''$.

The position and spacing of tracks in relation to structures or curves had, in many cases, to be analysed in detail, taking into account car throw-out and cant due to superelevation. With concentric curves, this analysis gives the distance between

centres of curves $D = 12 + \frac{660}{R} + \frac{e}{6}$ where e is the amount by which the outer curve superelevation exceeds that of the inner curve, the displacement of tunnel centres in curves being $\frac{4}{3}\,e$.

For this work, plans with accurate co-ordinate lines on a scale of 2 feet to one inch, have been used and it has been found, providing, of course, that the work has been carefully executed, that co-ordinates can be scaled to within one quarter of an inch thereby saving much time in difficult cases. All tangent points and the centres of all curves being co-ordinated, form a basis from which the detailed construction plans are drawn and the work finally set out in the field.

As practically all subsequent work depends on the mathematical exactitude of the track centre lines, it has been essential that certitude of the calculations be obtained. Ordinary methods of computing and checking, by another computer repeating the work, have been discarded, and a method adopted by which all the tracks calculations are automatically self-checking.

The route mileage of the City Railway from Redfern back to Redfern is five miles, 22 chains, and the track mileage 17 miles, 69 chains.

4. *Train and Passenger Capacity.*

Based on a 30-second station stop, an acceleration of $1\frac{1}{2}$ miles per hour per second, a deceleration of $1\frac{3}{4}$ miles per hour per second, and a speed of 35 miles per hour with the continuous overlap system of signalling and automatic train stops, the capacity of each track within the City is 36 trains per hour, or 360 per hour for the complete system, each of which, on account of the design of the system, two loops and one pair of through tracks, on reaching the City, sets down or picks up passengers to and from the City.

When required speed control can be introduced and the capacity increased about 16 per cent., *i.e.*, 42 trains per hour per track, or 420 trains in all per hour, representing a passenger capacity of 500,000 hourly. The evening rush hour traffic is about 15% of the total daily traffic, and when the capacity of 500,000 per hour is reached the daily traffic will be about 3,300,000, or, based on 339 travelling days per annum, a yearly number of 1,100,000,000. Assuming the number of rides per head of population per annum at 550, the system

will be adequate for a population of over 2,000,000 in the Metropolitan area. These figures indicate that the whole of the work under construction and proposed should be undertaken now to cope adequately with the traffic 15 years hence.

Fig. 3.—The City Railway.
Diagrammatic Layout showing first section to be opened for traffic.

5. *Time of Journey.*

The time of journey from Central station around the loop and back to Central station, with a 30-second station stop at Wynyard Square and a 20-second stop at all other stations will be 11 minutes, 38 seconds, the distance being 3 miles, 63 chains. The longest distance between stations is St. James to Quay—0 miles 71.3 chains, the running time being 2 minutes 10 seconds.

When the section to St. James is opened for traffic passengers will reach St. James in 2 minutes, 35 seconds from Central, about the same time or less than it now takes them to disembark from the train at Central and board the tram there.

6. *Section I.—Construction.*

The work now described in detail is the construction of the first section of the City Railway from Cleveland Street bridge to St. James station, a distance of 1 mile 37 chains.

This construction will bring two electric tracks into the City as far as St. James, which will be a temporary terminal station. As shown on Fig 3, two lines of railway take off from the existing railway system to the north of Redfern station, adjacent to the Wells Street overbridge and run parallel to the existing railway as far as Cleveland Street, where the tracks curve to the east and, by means of the flyovers, traverse the eastern side of the existing railway yard, to the new Central station. This open

air station is situated on the eastern side of the main building, with platforms levels about four feet above the existing platforms. Continuing northwards, the two tracks cross Eddy Avenue on a reinforced concrete girder bridge, then traverse the eastern side of Belmore Park, cross the Hay and Campbell Street bridges, then pass in tunnel under Goulburn Street, reaching Museum station at a level of 45 feet below the surface. The two lines then continue under Hyde Park to St. James station which is situated at the extreme northern end of the park. The tracks extend beyond the station under Macquarie Street to allow for shunting the longest train, during the time St. James is a temporary terminal station.

In the following detailed description of the various phases of construction, the chronological order in which the work was carried out has not been observed.

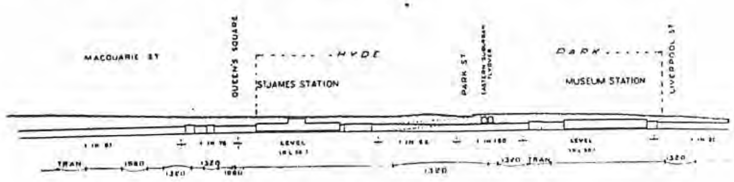


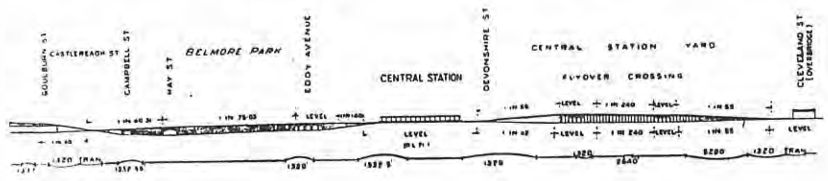
Fig. 4.

Cleveland Street Bridge.—The alterations to Cleveland Street bridge, Fig. 5, necessitated the construction of three additional double-track arch spans providing 6 additional tracks to Central station, making 14 tracks in all. The main water supply for Sydney and the eastern suburbs, in pipes of 36 in. and 42 in. diameter respectively, is carried under the tracks at this point and before work could be proceeded with on the foundations for the additional arches, it was necessary to carry the pipe tunnel well past the site of the new eastern abutment. This work was undertaken by the Metropolitan Water, Sewerage and Drainage Board, and completed as indicated on Fig. 6. The tunnel was 11 ft. 0 in. wide, with side walls and segmental arch in brick, supported on a heavy concrete floor. Access to the pipes was afforded by a new manhole and chamber constructed on the eastern side.

The new bridge arches have a clear span of 25 ft. 6 in. with a central height of 19 ft. 0 in. and a width of 139 feet; a segmental ring of four rows of brickwork, with an inner radius of 16 ft. 6 in. and a rise of 6 ft. 0 in. Concrete backing is laid

over the haunches to a depth of 4ft. 6 in. and sloped back to the crown of the arch. The roadway is of wood blocks laid on a bed of 6 in. concrete over the filling, the road surface being 1 ft. 8 in. above the top of the crown. Work was commenced on the southern half of the bridge, the tram lines were moved over to the north side and slightly more than half of the roadway was fenced off, ample room, however, being left to maintain the roadway traffic. All material had to be removed at road level as the longest period of clear railway track never exceeded 30 minutes, the whole of the work being carried out during the usual working hours.

The new piers have a width of 3 ft. 6 in. and were built up to the springing line of the arch, before the demolition of the existing single track eastern arch was begun, and extended to a little more than half the width of the bridge. The dismantling



(*Continuation of Fig.* 4.)

of this old 18 ft. 0 in. arch, which consisted of four brick rings in cement, was done by cutting away the three top rings almost to the haunches, leaving only one brick ring standing, which was finally removed as the new arch advanced.

The erection of the new arch ring, with its span of 25 ft. 6 in. was simply a problem of how to support the centering,—no propping or support from the ground could be used, as normal railway traffic had to be maintained throughout the whole construction. The weight of the arch ring per lineal foot was about 7,000 lbs.

Fig. 7 shows the method adopted.

Steel rails were bent to the required radius and seated on the sandstone skewbacks at centres of 3 ft. 0 in. From the flange of the rail, 3 in. × 2 in. timber forming was suspended by $\frac{3}{4}$in. bolts, the upper surface curved to form a seating for the $3\frac{1}{2}$ in. × $2\frac{1}{2}$ in. lagging; the centering was placed at a distance

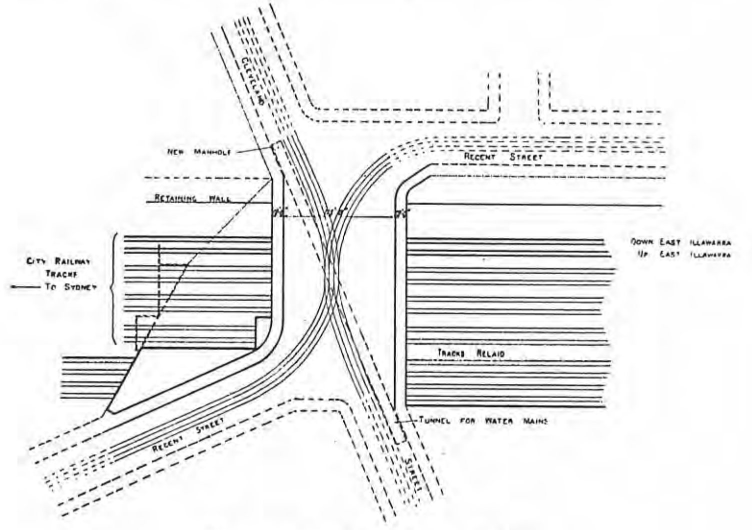
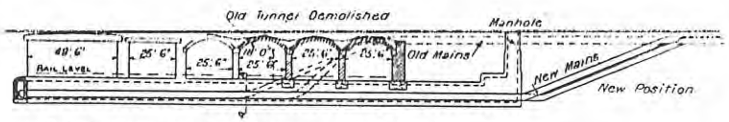
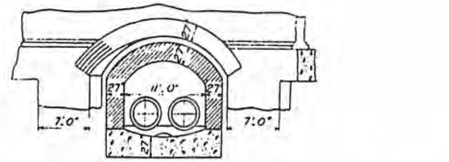


Fig. 5.—*Cleveland Street Bridge.*



CROSS SECTION SHOWING NEW ARCHES AND EXTENSION OF WATER MAINS TUNNEL

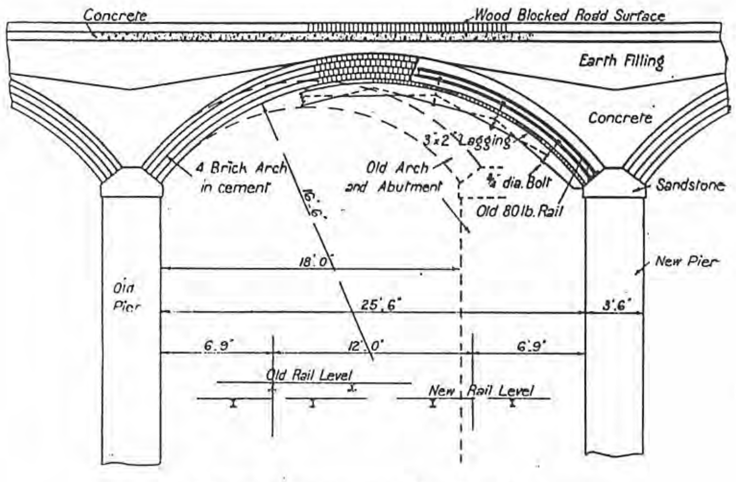


ENLARGED SECTION AT A-A
SHOWING TUNNEL WALLS ARCHED OVER WATER MAINS TUNNEL

Fig. 6.—*Cleveland Street Bridge.*

sufficient to enable the first course of brickwork to pass beneath the flange of the rail. After the completion of the four courses of brickwork forming the arch ring, the centering was withdrawn and the bolts cut, the rail remaining inside the arch ring. The remaining arches were constructed on centering supported from the ground.

The concrete foundations of the piers and abutments were carried down to hard shale and a relieving arch built over the water main tunnel.



METHOD OF CONSTRUCTING NEW ARCH RING

Fig. 7.—*Cleveland Street Bridge.*

At the completion of the work on the southern side, the temporary fencing on the roadway was moved slightly to the south and the tramlines shifted over to the new roadway, so that work could be started on the northern side. This half of the work was carried out precisely as the southern portion, on the completion of which the roadway was restored and the tramlines once more moved to their central position.

The gas mains, telephone cables and electric feeders met with just under the road surface had been suspended in their original positions while the new work was in progress, and finally installed in the new roadway.

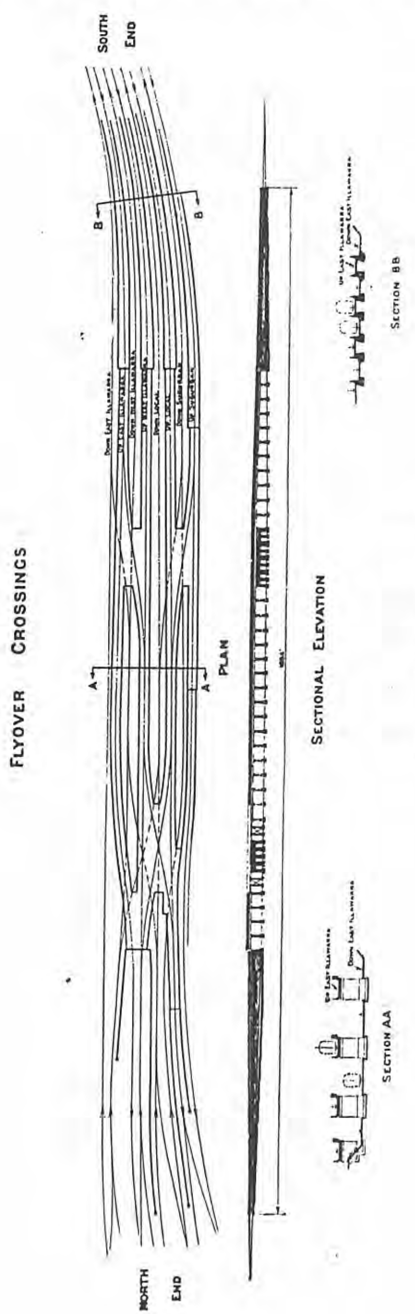


Fig. 8.—Fly-over Crossing.

The Fly-overs. (Figs. 8 and 9).—The work necessary in clearing the ground for the construction of the new fly-over crossings, was considerable, as practically the whole site was occupied. The large carriage shed, many lines of trains storage track, with the Signal Engineer's Workshops, covered most of the site. Excavation for the fly-overs extended almost from Cleveland Street bridge to Devonshire Street subway.

The actual design of the structure (Fig. 8) was governed by several factors, among which were the rail levels at Cleveland Street bridge and New Central station, which were fixed.

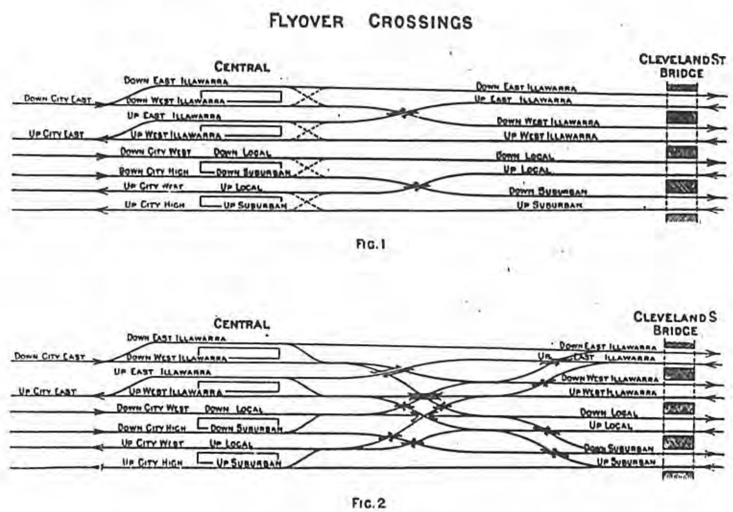


Fig. 9.—Fly-over Crossings.

The fly-overs were designed for a height from low level to high level rails of 21 ft. 3 in., so as to provide the necessary head-room. The depth of general excavation was limited by the Prince Alfred Park sewer, which, lying not deep in the ground, had to be diverted to a point in Balfour Street beyond Tooth's Brewery.

The superstructure was laid out to afford a maximum of simple construction and repitition work and consists largely of simple steel beams encased in concrete and supported on brick piers, carried on concrete footings. Where, on account of crossings, this construction could not be followed, it was replaced by a series of skew spans consisting of plated girders

carrying stringers encased in concrete. The piers of this construction have openings left in them for economy. The approaches to the superstructure consist of embankments between retaining walls.

The piers are spaced at 24 ft. 0 in. intervals and have an average width of 3 ft. 6 in. with a maximum height of 20 ft. 0 in. The track is carried from pier to pier on 24 in. × 7½ in. rolled steel joists spaced 3 ft. 0 in. centres, held to position by bolts passing through the webs. The floor is supported by concrete jack arches between the joists, having a minimum thickness at the crown of 16 in. The floor is waterproofed with bitumen and the water led to drainage gratings to ensure a perfectly dry track.

The greatest care was necessary in the setting out of the piers, in fact, the whole construction was one of careful alignment.

The foundations of the piers and retaining walls at the north and extreme southern ends of the fly-overs gave no concern whatever, as good hard shale was found a few feet below the surface, but at the centre portion the shale petered out, the foundation being a mixture of poor ironstone and clay. The pier bases were therefore carried down some five feet into the clay, reinforced with old rails and spread sufficiently to ensure a pressure not exceeding 1½ tons per square foot.

When completed, the construction of the fly-overs will have employed some 4,500,000 bricks, 8,000 cubic yards of concrete and 1,200 tons of steelwork; whilst the excavation has amounted to over 83,000 cubic yards of shale, clay and sand.

Two steam shovels were used in the excavation, each with a dipper of ¾ cubic yard capacity. These machines have kept eighteen motor lorries busy removing soil to the upper end of Darling Harbour. Here the spoil from the City Railway will, together with certain resumptions along the eastern foreshores, provide an additional 23 acres of land for the extension of Darling Harbour Goods Yard.

Prince Alfred Substation.—Adjacent to the northern end of the fly-overs on the eastern side, is situated the new Prince Alfred substation. The cable ducts from the western side of the tracks pass under the fly-overs and are accessible through deep level manholes. These manholes and chambers connecting the ducts are formed in plain concrete, the deepest being some 25 ft. 0 in. from cover level. Three-phase current at 6,600 volts is here transformed to traction current at 1,500 volts, D.C. and is transmitted to the overhead catenary system.

Devonshire Street Subway.—Before starting work on the alterations to Devonshire Street Subway, a water main tunnel was required to house the three lines of water supply piping which cross the station yard from east to west. This tunnel was constructed with 18 in. brick side walls and concrete roof and floor, reinforced with 80 lbs. rails at 18 in. centres, having a clear width inside walls of 5ft. 0 in. and a height of 6 ft. 0 in. A 21 in. diameter E.W. pipe line was connected from the tunnel to the adjacent sewer so as to provide drainage from the tunnel in the event of one of the water mains bursting.

The designs of the new Central station, with the entrances to the southern concourse from Chalmers Street and the western side of the present station, made it necessary to straighten out and extend the existing 20-feet wide Devonshire Street subway, which connects George Street and Chalmers Street.

The length of the subway affected was some 257 feet, at the eastern end, giving access to Chalmers Street. The old subway was open for this distance, but it was necessary to roof the new work for a length of 150 feet, to carry the new tracks of the City Railway. From Chalmers Street up to this point, the subway was open with gravity walls in brick, carried on concrete foundations supported on hard shale. Bands of disintegrated charcoal were encountered during this excavation. The covered portion of the new subway has side walls of reinforced concrete 18 in. thick, with ¾ in. diameter vertical bars at 10½ in. centres and ½ in. horizontal bars, spaced 9 in. apart on inner surface and 18 in. on outer. These walls were designed as fixed beams with transverse footings supported on concrete piers taken down to hard rock. Rolled steel joists, 16 in. × 6 in., spaced 21 in. centres, encased in concrete, form the roof of the subway carrying the tracks, whilst in the two available spaces between the tracks are installed large prism vault lights, 17 ft. 6 in. long and 12 feet wide, giving ample natural light to the subway. The walls and roof are entirely waterproofed with ¾ in. mastic asphalt protected with brickwork. The inner walls are faced with a cream glazed tile and the floor graded and finished with asphalt. The open section of the subway is ramped 1 in 13 and terminates in two flights of steps of easy rise, giving access to Chalmers Street, while the covered portion connects the open section to the old subway with a grade of 1 in 70.

Pedestrian traffic was maintained during the construction by diversion at a point adjacent to the old tracks, through a stairway leading to surface level, a rise of 12 feet and by a passage way fenced off on the northern side of the old subway.

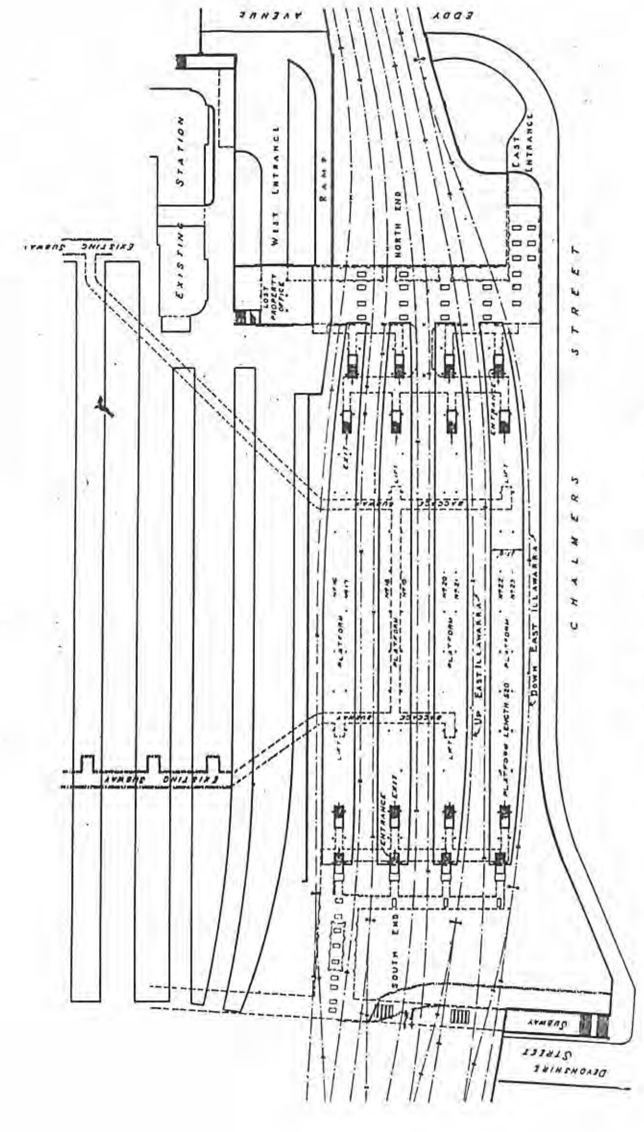


Fig. 10.—*New Central Station.*

The City Council carried out concurrently the work of diverting the electric cables to the new alignment.

Central Station.—The layout of this station is shown by Fig. 10. The four platforms served by stairways from subway concourses at the north and south ends are each 520 feet long with a maximum width of 33 feet. The roofs of the two platforms completed are of steel supporting a reinforced concrete slab. The roof columns are spaced 38 feet centres in pairs, 12 feet apart, and make practically no obstruction to the traffic on the platforms. A 3-ton electric goods lift is provided on each platform to convey passengers' baggage to a 10-feet baggage subway, which connects with the existing baggage subways at Central station, soon to be the steam long-distance terminal station. These new baggage subways were tunnelled under the existing railway tracks through hard rock and have a flat top construction of old rails, spaced 2 feet centres encased in 18 in. of concrete; the side walls are plain concrete 2 feet thick. The clear height inside is 8 ft. 6 in.; the subways drain into the present pipes in the existing baggage subways. At the junction of the subways and the connections to the lift wells, rolled steel joists, 10 in. × 8 in. are substituted for the old rails in the roof.

The stairways leading to and from the platforms and the northern concourse have a width of 7 ft. 6 in. and a total rise of 19 ft. 6 in. the entrance and exit stairways, and subways are independent of each other so as to avoid interference between passengers moving in opposite directions—separate entrances and exits are one of the special features in the stations on the City Railway. The northern concourse is 307 ft. 11 in. long, with an inside width of 55½ feet and is immediately under the tracks. An entrance, 30 feet wide, leads down from Chalmers Street on an easy grade of 1 in 13.7, while a western entrance gives direct communication to the concourse from Eddy Avenue. A 12-ft. stairway in the western corner of the concourse connects the old station with the new. The entrance in Chalmers Street is of classic design, consisting of a quadrant of Greek Ionic columns, 15 ft. 9 in. high, with entablature, all in sandstone. The inner walls are also of the same material with Greek Ionic pilasters and panelling.

The entrance and exit subways to the platforms are on the southern side of the concourse, leaving a clear way of some 43 feet for passenger movement. The whole structure is built in reinforced concrete, the side walls, columns and roof being designed to take the heaviest train loads. Columns, 2 feet square, are spaced at 15 feet intervals with heavy girders con-

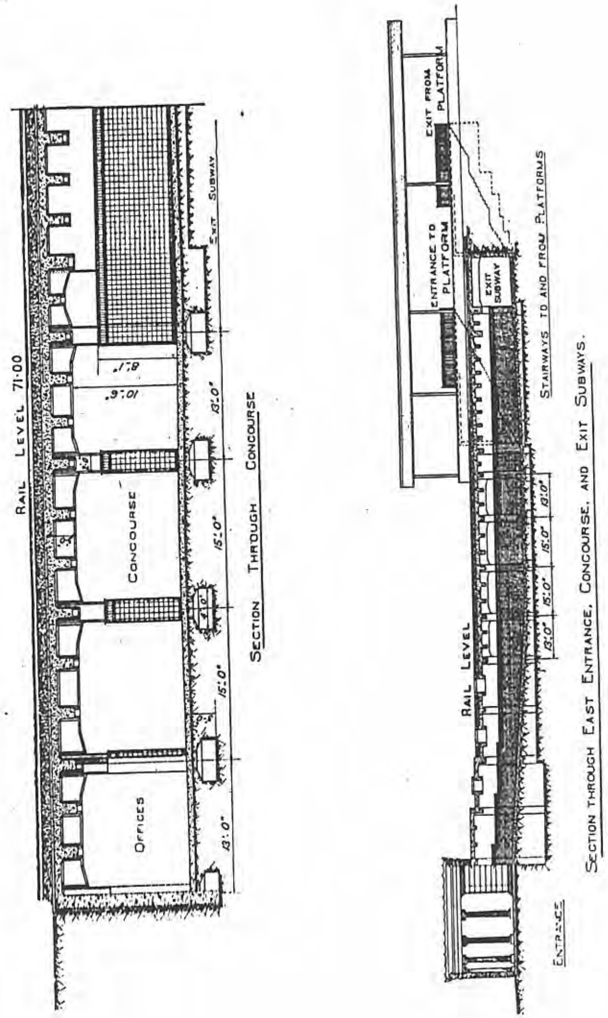


Fig. 11.—New Central Station.

necting them together; the girders are at right angles to the side walls; the transverse beams with a span of 14 feet are spaced at 5 ft. centres and support the 9½ in. and 6½ in. roofing slabs.

The slabs are 9½in. thick under the live load and 6½ in. thick over bays carrying dead load only.

The structure, as far as possible, was built monolithic; where construction joints occur precaution was taken to ensure continuity of the work.

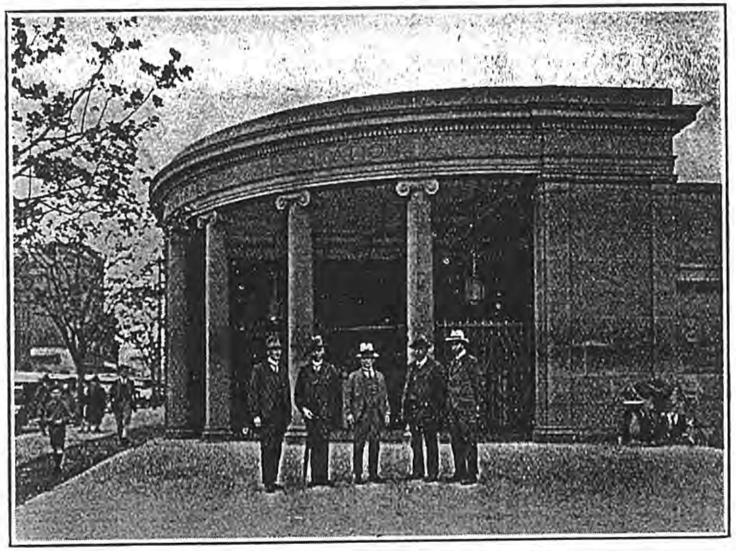


Fig. 12.—Chalmers Street Entrance to New Central Station.

The greatest load on any one column is 114 tons, giving a unit stress of 640 lbs. per square inch compression.

The footings were carried down to rock and the bases made 4 ft. square, giving a bearing pressure of 7¼ tons per sq. foot.

The side walls, designed as fixed beams, have a thickness of 15 in. and are reinforced with ¾ in. vertical bars at 6 in. centres. To provide for expansion and contraction due to temperature, ½ in. bars were placed horizontally at 9 in. centres on the inner face and 18 in. centres on the outer face.

Construction began by pouring the column bases up to the bearing plate of the main column bars, followed by the plac-

ing of the reinforcement and the shuttering of the columns, which were then poured to the height of the underside of girders. Simultaneously the side walls were carried to the same height The timbering and centering for the girders, beams and slab, was then erected in bays the full width of the concourse, and the reinforcment placed in position. The pouring of the roof (girders, beams and slab) was continuous over as large an area as possible in order to eliminate the number of construction joints. The walls and roof are covered with mastic asphalt, ¾ in. thick, placed in two layers to ensure watertightness of the station, the waterproofing being further protected with a cover of brickwork, in 3 to 1 cement mortar.

Air ducts have been provided in all the offices and lavatories and a system of ventilation installed which should maintain a pure atmosphere under all conditions.

The concourse at the southern end of the platforms is much smaller than at the northern end; it connects the two 12 ft. subways which give ingress and egress from the platforms, to the reconstructed Devonshire Street subway. It will be constructed in reinforced concrete of a design similar to the northern concourse.

Both concourses receive considerable natural light from large prism vault lights in the roof, so minimising artificial lighting. The side walls, subways and columns are finished with cream tiles to a height of 8 feet and the floors asphalted 1¼ in. thick over a 6 in. concrete base.

The lost property office built over the western entrance has a length of 78 feet and extends the full width of the concourse. The roof is of reinforced concrete, the side walls of brick; the outer face wall of sandstone extends to concourse floor level and makes a feature of the western entrance from Eddy Avenue.

To deal with the stormwater from the platform roofs and track drains, an extensive system of reticulation was necessary. On account of the impervious nature of the catchment, provision was made for a run off of 6 in. rainfall per hour within the station limits; outside the station limits a run off of 3 in. per hour was decided upon.

To deal effectively with the run off from roofs, tracks and also seepage, the stormwater drainage was so arranged that the southern half drained into the 3 ft. stormwater sewer alongside the Devonshire Street subway and the northern half into the 4 ft. 6 in. by 3 ft. 0 in. sewer in Elizabeth Street at the corner

of Foveaux Street. The pipes used varied in diameter from 6 in. to 21 in.

The portion of track drainage from Central station to Goulburn Street and from Museum station is intercepted at the lowest point of the ease on the Up and Down City East tracks in the tunnel under Elizabeth Street, near Goulburn Street, and diverted by a 9 in. line to the stormwater sewer in Castlereagh Street.

Provision is also made for the subsequent interception of track drainage and seepage from the western tracks at Goulburn Street.

The sewerage from Central station presented no unusual difficulties. A 6 in. pipe was used for connecting up with the existing 9 in. sewer, alongside the old station, which in turn discharges into the Bondi sewer below Eddy Avenue.

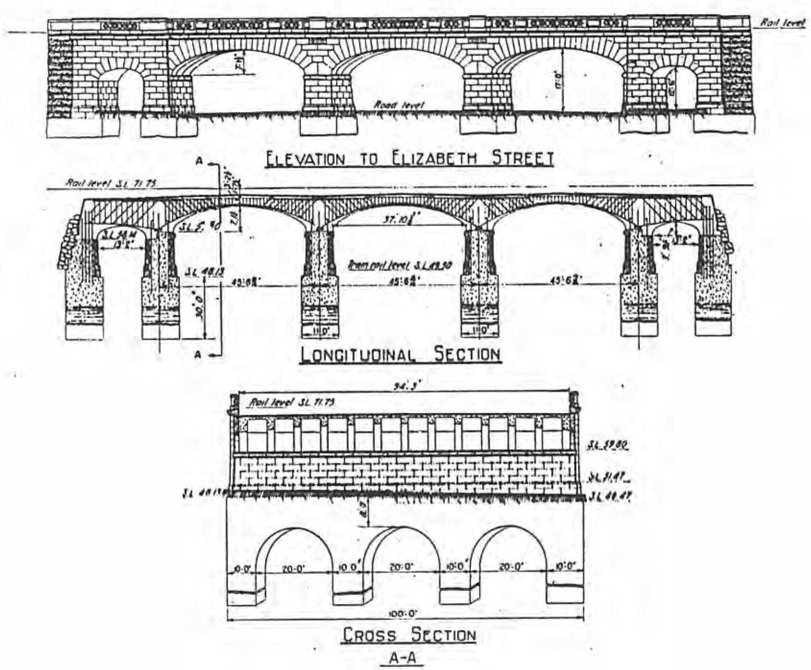


Fig. 13.—Eddy Avenue Bridge.

Eddy Avenue Bridge (Fig. 13).—The tracks from Central station cross at an elevation of 21 feet above Eddy Avenue on a reinforced concrete girder bridge consisting of 3 roadway and 2 footpath spans.

The reinforced concrete is faced with sandstone masonry. The bridge piers and abutments are constructed parallel to the kerb line on the northern side of Eddy Avenue and the distance to the centres of piers and faces of abutments measured from this kerb line. The two footpath spans have a clear width of 12ft. 3 in. and the three road spans 36 ft. 2 in.

Seven tracks are carried over the bridge, which has a width inside parapet walls of 94 ft. 3 in.

The intrados of the span is elliptical in section, the bridge being constructed as a series of continuous reinforced girder ribs carrying a reinforced concrete floor. The ribs over the roadway spans are spaced at 7 ft. 8 in. centres, with a width of 25 in. and have a depth over the piers of 9 ft. 7½ in., diminished to 3 ft. at the crown. Continuing over the footpath spans the ribs are securely anchored to the abutments. The reinforcement at the crown of the large spans consists of 16 one inch diameter steel bars, giving an area of 12.57 square inches. The moment at the centre of the span is 6,691,800 inch-lbs. Treating the section as a T section, with the floor slab 10 in. thick and the width 7 ft. 8 in. (the centres of the ribs), the total stress in the concrete is 501 lbs. per sq. in. with a steel stress of 17,900 lbs. per sq. inch. The moment at the abutment is 13,383,600 inch-lbs. stressing the four one inch bars provided to 18,000 lbs. per sq. inch, while the stress in the concrete does not exceed 490 lbs. per square inch. The total shear at the abutment is 147,920 lbs., one-third of which will be taken by the concrete and the remaining two-thirds by the bent-up steel main bars and steel stirrups.

The piers and abutments are of ordinary concrete, faced with masonry, with sets of bar reinforcement under the seating of the girders for anchorage. The piers have a width at the base course of 8 ft. 0 in. and the abutments of 9 ft. 4½ in.; the distance to the springing line of the roadway arches from top of pier foundations is 11 ft. 8 in.

A commencement was made at the north abutment; the excavation was taken to a depth of 29 ft. 0 in. before hard bed rock was obtained. Piers, 10 ft. 4½ in. by 6 ft. 0 in., at 19 ft. 6 in centres, were sunk down to this level, with segmental arches between, having a crown thickness of some 8 feet below the base course of the pier proper. At the western corner of the foundation, the Bondi sewer passed at a depth of 12 feet below the surface and a relieving arch was thrown over and the foundations continued to take the wing wall connecting the present tramway bridge with the new work.

Continuing the foundations at the eastern end of the abutment, the return was made to suit the Elizabeth Street retaining wall. Concrete was poured to the level of the pier base course and left at this stage until the completion of the foundations of the southern abutment and the two inner piers of the footpath spans had attained the same height. No trouble was encountered in the sinking of these piers, though the foundations of the southern abutment had to go down 32 feet before hard rock was found. This was the deepest excavation necessary and the rock met with during the sinking was of the poorest.

The masonry faces were then built up to the level of the springing line of the footpath arches and the concrete poured. Core boxes for the anchor bars of the main girders were inserted and the bars afterwards placed in position.

Pedestrian traffic was now diverted outside the piers and the centering erected for the main girders and floor slab. The reinforcement was placed in position and the floor slab and girders poured for the whole width of the bridge, the reinforcement of course projecting into the road spans. The true elliptical arch was set off from template.

Excavation was now started on the two central piers and taken down to a depth of 30 feet. The piers were made 11 ft. by 10 ft. and brought up to within 10 ft. of the surface where, instead of the segmental arches between the foundations used in the abutments and inner piers, a decking of old rails was laid over the piers and the foundation carried up to the level of the base course. The reason for not arching was due to the difficulty of placing the centering in the very limited room available. The centre piers were then completed up to the springing line of the arch in the same manner as those previously described. A pressure of 10.8 tons per square ft. is allowed on these foundations.

The general vehicular traffic and traffic on the two tramway lines which pass under the centre span is at all times heavy, and the centering and supporting frame-work for the concrete ribs and flooring had to be designed to give the minimum of interference to traffic. A supporting timber trestle was erected close to the piers (Fig. 14) in each span and rolled steel joists at 7 ft. 11 in. centres placed in position, upon which the centering of the arch was erected. Thus, a clear roadway was left in

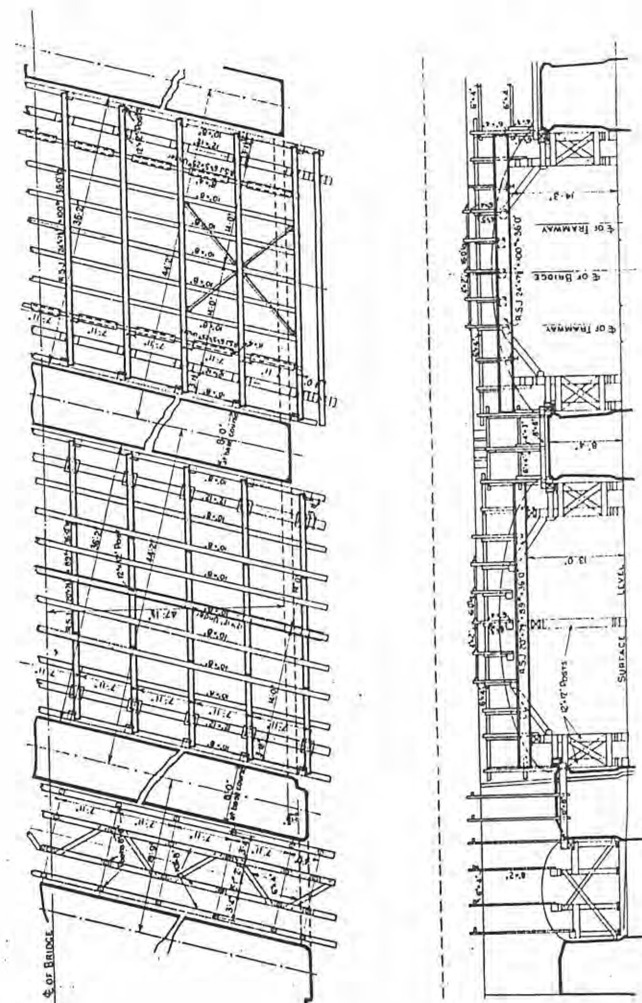


Fig. 14.—*Eddy Avenue Bridge—Centering.*

the centre arch, while the supporting frame along the centre of the side spans was really no obstruction but helped rather in routing traffic. The erection of the heavy rolled steel joists in the centre span was carried out after midnight on Saturday as no interruption to the tramway service was permissible. The 16 heavy beams, each 36 ft. long, were swung into position in 70 minutes. Two cranes at road level, one each on the off side of the pier, lifted the beams from the truck and placed them over the trestles, and the same procedure was adopted in the side spans with one crane. A hole was left in the floor slab at each bay for dismantling the joists after the arch was poured. The crane working from the bridge deck had a lifting chain passed through the hole in the slab and so lowered the beams on to the waiting trucks. This operation was also performed at night; the tramway trolley contact line was cut and the new troughing with trolley line fixed to the underside of the arch.

After the placing of the girder and slab reinforcement, the sandstone masonry facing was constructed on the centering and the concrete poured over the three roadway arches up to the construction joints over the outside piers. The electric cable ducts were placed on each side of the bridge and the necessary provision made for manholes and posts for the overhead structures.

The bridge floor was waterproofed with $\frac{3}{4}$ inch mastic asphalt and graded to downpipes taken under the floor, then down the piers of the footpath spans to discharge into the road gutter.

The roadway under the bridge and the corner leading to Chalmers Street were regraded and re-surfaced, the footpath being finished with an asphalt surface.

Elizabeth Street Wall (Fig. 15).—This gravity retaining wall, extending from Eddy Avenue to Hay Street, is built of ordinary concrete with a facing of sandstone (rockfaced) masonry, supported on concrete piers taken down to rock. The wall has a total length of 754 feet and a maximum height of 35 feet from top of parapet to bottom of first course. The parapet is graded 1 in 75 from the north abutment of Eddy Avenue bridge to the south abutment of Hay Street bridge; the masonry courses of the wall, however, remain horizontal. The face of the wall is battered to 1 in 48 and the buttresses spaced at intervals of 50 ft. $7\frac{1}{2}$ in. with a top width of 5 ft. increasing to 6 ft. $9\frac{7}{8}$ in. at the base. The concrete backing is 10 ft. thick at the base course, stepped up in 3 ft. courses to a top thickness 3 ft. 9 in. Weep holes are provided every 25 feet and the hand-

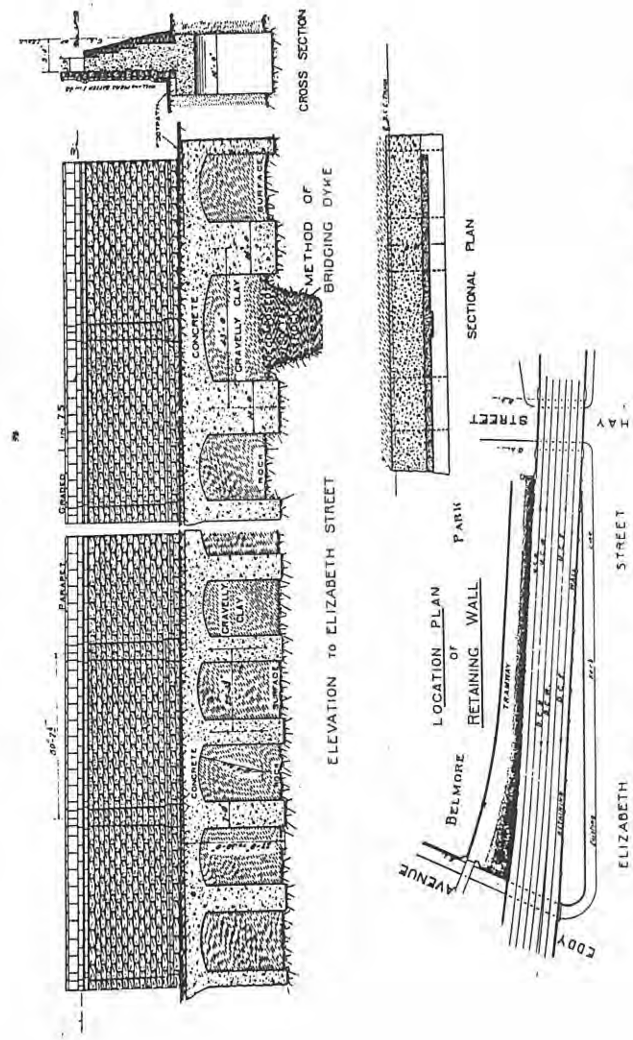


Fig. 15.—Retaining Wall in Elizabeth Street—Eddy Avenue to Hay Street

packed rubble backing has a thickness of 2 ft., thus ensuring a free drainage.

The equivalent surcharge from the train load was 3 ft. 9 in. above the base of the rail, and the rail 1 ft. 3 in. above the top of the wall, so that the total surcharge was 5 feet. The maximum tension in the back of the wall was 31 lbs. per square inch at a height of 24 ft. while at the base of the wall a pressure of 31 lbs. compression per square inch was obtained with no tension.

The foundations of the wall consist of segmental arches between piers taken down to hard rock, which was found at an average depth of 27 ft. below surface level. The span of the arches is 18 ft. $3\frac{3}{4}$ in. and the thickness of the piers 7 feet, the total width of the foundation being 16 feet. Where the wall crosses the Bondi sewer, which lies at a depth of some 12 feet below the surface, special provision was made in the arrangement of the foundation piers. An alteration had also to be made to the centering of the piers, on the opening up of a volcanic dyke some 20 feet wide, which passed under the wall midway between Eddy Avenue and Hay Street. Borings disclosed no bottom in the decomposed basalt so the dyke was bridged over from piers constructed on either side.

The maximum pressure on the foundation is limited to 20 tons per sq. ft. and it was found necessary to increase the width of the piers in the first four bays of the wall from Eddy Avenue to 18 feet, so that this pressure would not be exceeded.

Thirty shafts, each 18 feet by 7 feet, were opened and excavated to a depth averaging 27 ft. where hard rock was found suitable for the foundation piers. About 10,000 cubic yards of material were taken out of these shafts and the connecting trench for the arch, and used to form permanent filling for the embankment designed to carry the six tracks into the city.

The concreting of these shafts and the connecting arches forming the base of the retaining wall required upwards of 5,000 cubic yards of concrete before the surface was prepared for the sandstone masonry and concrete backing of the wall proper. The high-level embankment at the back of the wall was utilised for depositing concrete by gravitation, through adjustable chutes from the concrete mixers.

It was contemplated to construct a brick retaining wall on the western side of the embankment traversing Belmore Park. Borings put down along the side of the foundations for this wall, approximately parallel with the tramline from the Central station to Castlereagh Street, disclosed the fact that the volcanic

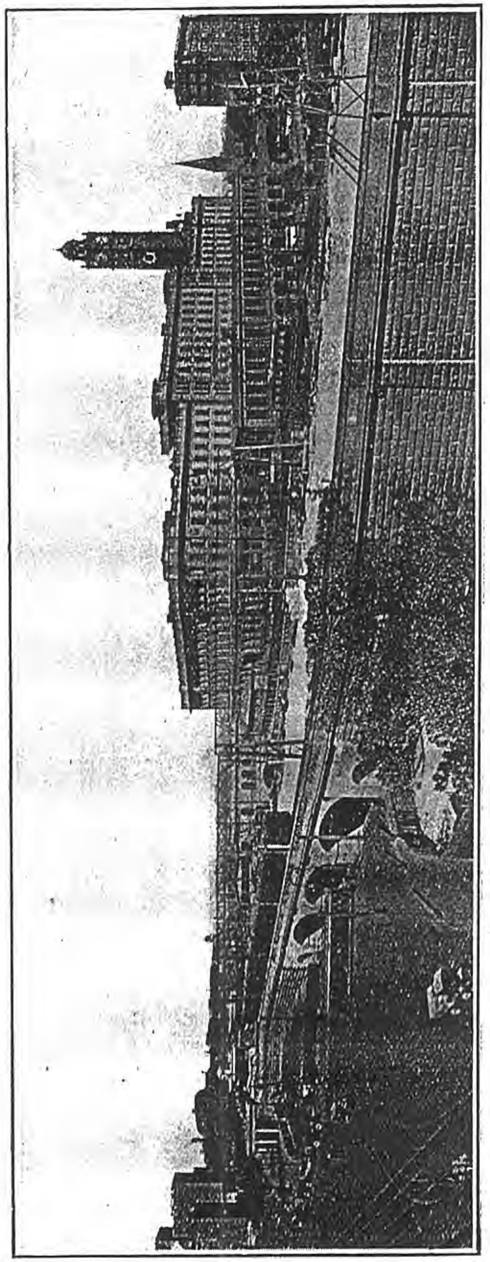


Fig. 16.—New Central Station, Eddy Avenue Bridge and Elizabeth Street Retaining Wall. Showing also original Central Station.

dyke found on the Elizabeth Street side of the embankment continued across and followed the general direction previously indicated; the width of the dyke, however, had increased considerably.

To carry across this dyke would have added considerably to the cost of the wall foundations, the estimate for which was already high owing to the depth required to reach hard rock. It was decided, therefore, to omit the brick retaining wall on this western side and to substitute a hand-packed stone wall pitched on a slope of 1 in 1. At the foot of this wall creepers specially selected for their clinging properties have been planted,—Ivy, Virginia Creeper, Climbing Fig, and Bignonia Tweediana often a mass of yellow bloom,—so in a few years time, this rubble wall will be hidden by a wealth of foliage, green and variegated, interspersed with golden yellow flowers.

Hay Street Bridge (Fig. 17). This arch bridge has a clear span of 81 ft. 8 in., with a width between parapet walls of 78 ft. 9 in., and was built in reinforced concrete, faced with sandstone masonry. The arch has a thickness at the crown of 24 in., reinforced top and bottom with $\frac{7}{8}$in. diameter bars at 4 in. centres. The intrados is a pure elliptic and the extrados five centered with a clear height from the springing line to the underside of the crown of 17 ft. 1 in. and a roadway clearance at centre of 20 ft. 9 in.

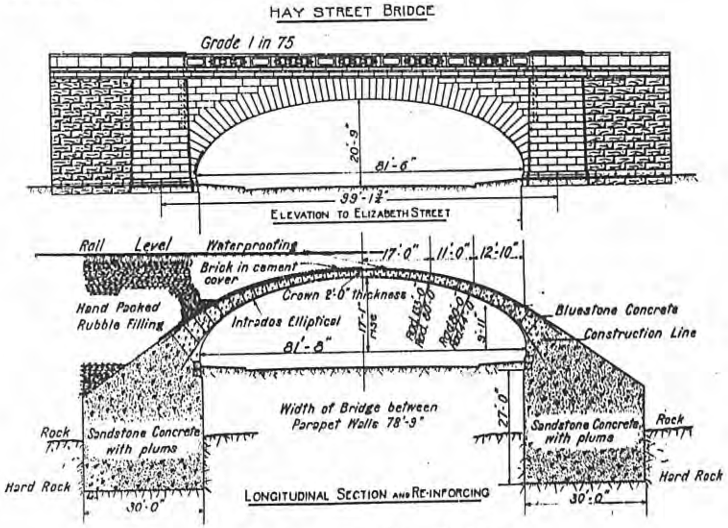


Fig. 17.—Hay Street Bridge.

The maximum stress in the arch ring occurs at a point adjacent to the crown and was found to be just under 500 lbs. per square inch for the concrete, with 7,500 lbs. stress in the steel, while the temperature stresses added another 150 lbs. to the concrete, making the total stress 650 lbs., per square inch.

The arch abutments, 30 feet wide, of sandstone concrete with plums, were taken down to hard rock, averaging a depth of 27 ft. giving a maximum pressure on the foundation of 10 tons per square foot.

The spandrel walls were built up to within 12 in. of rail level and had expansion joints at both abutments, covered with sheet lead and continuing through the parapet. The abutments were poured up to the construction joint shown on Fig. 17, with $\frac{7}{8}$ in. bars at 4 in. centres, embedded and left projecting from the concrete at the extrados and intrados of the arch to form an efficient bond. No difficulty was experienced in the erection of the staging for supporting the form work for the bridge, as the road was closed to traffic during the construction of this portion of the work. After the masonry facing was erected on the centering, the arch ring was poured in five sections, each having a width of 15 ft. 6 in. between construction joints, and employed 1,015 cubic yards of concrete; a section was poured each day, the actual working time being 32 hours in all.

The top of the arch was waterproofed with two $\frac{1}{2}$ in. coats of mastic asphalt, and covered with brickwork laid in cement before the hand-packed rubble filling was carried up to rail formation.

The roadways under this bridge and Campbell Street bridge were re-graded and re-surfaced, the footpaths being finished with asphalt mixture placed by the City Council.

Retaining Walls—Hay to Campbell Streets.—The retaining walls supporting the tracks across this block between the two bridges of Hay and Campbell Streets, has a total length on each side of nearly 155 feet with a maximum height above surface level of 27 feet. The design is similar in every way to the Elizabeth Street wall, with the procedure of construction the same.

All foundation piers were carried down to hard rock at an average depth of 25 feet, the end arches connecting to the bridge abutment foundations.

Campbell Street Bridge.—An arch bridge of 50 feet clear span, of like design to the Hay Street bridge already described.

At the crown the arch is 15 in. thick, reinforced with $\frac{3}{4}$ in. diameter bars at 8 in. centres, top and bottom. The intrados of the arch is elliptical, with the extrados three centred, with a height of 10 ft. 6 in. from springing line to underside of crown.

The bridge has a clear height from road surface of 14 ft. 10 in. The dead and live loads will produce a compression stress in the concrete at the crown of 371 lbs. per square inch, and in the steel a tensile stress of 5,240 lbs. per square inch; whilst secondary stress increases these to 563 lbs. and 14,740 lbs. per square inch respectively. The sandstone concrete abutments, 24 ft. wide were taken down to hard rock 25 ft. below the surface; giving a maximum pressure on the foundation of $8\frac{1}{2}$ tons per square foot. The erection of the timber centering, pouring of the concrete arch and finish of the bridge, were in all respects similar to the Hay Street structure.

It was originally intended to erect a building on the block between Campbell and Goulburn Streets for the Commissioner's Railway Offices, and a commencement was made on the excavations and the preparatory foundation work for the erection of the steel columns to carry the building; however, as this building is in abeyance at the present, it was decided to leave the site as it is and complete the track work only.

Goulburn Street.—At the south side of Goulburn Street, some 31 feet below street level, a cable transfer tunnel has been constructed under the six tracks.

The tunnel has a width of 6 feet, with 7 feet clear head room and is constructed in plain concrete, the roof under the tracks being reinforced with 10 in. x $4\frac{1}{2}$ in. r.s. joists, the floor concreted and drained. Six manholes give connection to the tracks and access to the tunnel and are situated in the track tunnel walls, with ample clearance for safe working. This tunnel gives the utmost flexibility in the interchange of cables, the ducts on either side of the tracks having direct communication with any one of the six tunnels. Provision has also been made in the extension of the tunnel into the street area, so that at any time connection may be made from this quarter.

A 24 in. water main crossing Goulburn Street between Castlereagh and Elizabeth Streets, also a private 12 in. pipe, had to be diverted to give clearance to the tunnels. The new pipes are now nested in the roof of the tunnels, at the northern side of the street. Rolled steel joists encased in concrete form a safe support for the passage of the mains. The 24 in. pipe,

running parallel to Elizabeth Street, had also to be diverted in order to clear the Down City tunnel. These diversions were made and completed by the Metropolitan Water, Sewerage and Drainage Board and the diversion of the H.T. electric cables on the southern side of the road was carried out by the City Council.

Goulburn Street to Museum Station.—From the south side of Goulburn Street, the Down City East and Up City East Tracks proceed north in twin tunnel construction under Elizabeth and Liverpool Streets, emerging at Museum station, a distance of some 740 feet, with a rail level of 45 feet below the surface.

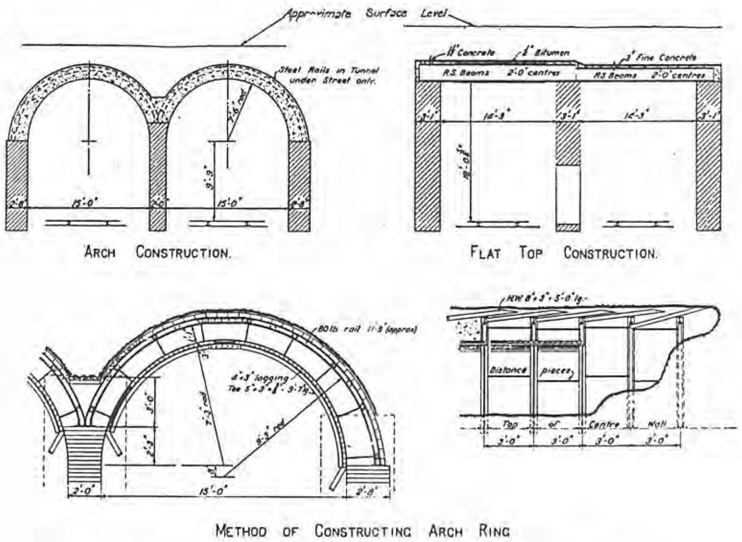


Fig. 18.—*Twin Tunnels between Goulburn Street and Museum Station.*

From Fig. 18 can be seen the two types of construction employed for the roofing of the tunnels.

The concrete arch construction, with centre and side walls in brickwork, extends from both ends of this section (Goulburn Street and Museum station) to a point immediately under the street buildings on the western side, where for a short length, connecting the arch constructions, the flat top construction is employed, consisting of rolled steel beams encased in concrete.

The tunnels have a clear width of 15 feet for the arch section and a height of 9 ft. 9 in. to the springing line of the roof, which is semi-circular to a radius of 7 ft. 6 in., giving a total height from rail level to crown of arch of 17 ft. 3 in. The walls of the flat topped section were increased to a thickness of 3 ft. 1 in. and the width of the tunnel reduced to 14 ft. 3 in., the height, however, remaining as for the arch section.

The method of constructing these twin tunnels to pass under and near to the walls of Mark Foy's Furniture Warehouse at the corner of Liverpool and Elizabeth Streets, differed materially from the methods of tunnelling adopted on the other sections.

In order to clear the steelwork at Museum station, and also near Goulburn Street, the distance between track centres had to be not less than 17 feet. To have constructed a double track tunnel an excavated width of not less than 37 feet would have been required. Borings showed that the nature of the material to be excavated was chiefly clay and soft shale on top, with very hard rock below.

From the top of the tunnel arch to the road surface of Liverpool Street, with its very heavy vehicular traffic, was 14 feet, and only 11 feet in Elizabeth Street near Goulburn Street.

The corner of Mark Foy's Furniture Building carried a load of 145 tons and was directly over one side of the tunnel, whilst further along the corner column of this firm's main building, supporting 250 tons, was immediately over the other side wall.

To have built a single tunnel for the two tracks by the usual methods would have been a very difficult, not to say dangerous, undertaking. A large area would have had to be opened up and heavily timbered, the bad combination of shale in the roof and the hard rock bottom, making things anything but easy It was, therefore, decided to construct the twin tunnels already described.

Commencing from the Museum Station end, three bottom headings were driven on the line of the three walls of the tunnels. The two outside ones were 10 ft. 6 in. high from rail level by 4 ft. wide and the centre one was the same width but 2 ft. 3 in. higher. These headings were timbered by means of squared sets, using 8 in. x 5 in. sleepers for caps, and 8 in. x 5 in. hardwood legs, being close lathed on the roof and also down the sides to where the rock started. They were driven in first of all for a distance of 100 feet, before the bricklayers were started on the wall at the extreme ends

of the headings. The side walls were made 2 ft. 8 in. thick and finished at the springing line of the arches. The centre wall was 2 feet thick and was carried up to 2 ft. 3 in. above the springing line, thus giving a 3 inches overhang on each side at the top of the wall. After the completion of the 100 feet lengths of these walls, the excavation of the arched portion of the tunnels was commenced.

To carry the overburden on this section during construction, instead of the usual form of timbering with crown-bars, etc., curved steel rails were used. Centres were made up of 80 lbs. steel rails and were curved to the outside radius

Fig. 19.—Commencement of Underground Construction—Goulburn Street.

of the tunnel, there being two pieces of rail to each tunnel or four pieces in the set. These centres, spaced 3 feet apart, were connected together with fish-plates and bolts and then seated on bearing plates over the walls. Excavation of the arch was afterwards made for a distance of 3 ft. and a second set of rails erected. Bridging pieces, some 2 ft. 6 in. long, were cut out of hardwood to suit the radius of the curved rail. These were blocked up and hardwood laths driven on them from the top of the first rail set.

Special care was taken in the packing of all cavities above the laths and seeing that all bolts were screwed up tightly.

Following the first set, when some 18 inches of excavation had been removed in front of the rail, the laths were threaded under the bridging pieces and driven ahead as far as possible and the back ends wedged down from the laths in the set behind. This maintained the ground above, while the next 18 inches was excavated and the rail placed. The laths and cap pieces in what had been the three wall headings, were recovered as the driving of the arch proceeded and the spoil from the arched portion was allowed to run down and fill up the space between the walls and the sides of the headings. The balance of the spoil was filled into skips and run out to the face of the tunnels, where it was finally disposed of by cranes and lorries.

After driving about 18 feet of the arch, work was at once started on the concreting of a 12-feet length of both arches. This was done without interfering with the driving. Angle cleats with a ½ in. hole in each had been riveted on to the web of the curved rails, there being 10 to each set in each tunnel. Half inch tie bolts of sufficient length with nut and plenty of thread on each end, were hung through the holes in the cleats. On to these was fixed a "T" iron curved to a radius of 3 inches less than the finished radius of the arch. These "T" irons carried the 3 in. oregon lagging on which the concrete was placed. The two tunnels were concreted simultaneously, the concrete being mixed on the surface and conveyed by chutes into skips which were wheeled in, and tipped on to a board below the section under construction. The concrete was then shovelled up into position above the laggings, the curved rails and laths being left in. The average thickness of the arch ring was 18 in. The finished section of the tunnel was always maintained close behind the driving, thus giving the shale above no chance of disintegrating through exposure to the air. So soon as the driving and concreting of the arches had been completed up to the end of the first section of the brick walls, the driving of the headings was recommenced and about another 100 feet of brick side walls constructed. Ramps on a grade of about 1 in 5 were made, leading from the springing level to the end of the walls for hauling up the spoil, and the driving of the headings, building of the walls, and concreting of the arch were continued as before. The only alteration to this procedure was made when the driving of the arch was approaching the pier of Mark Foy's main building. The foundation of this pier was known to be very close to the side of the arch, and in order to take the additional loading the distance between the rail sets was reduced from 3 feet to 2 feet for some 10 feet previous to

reaching the pier. This spacing was again reduced to 14 in. for 6 feet directly under the pier and then opened out again to 2 feet over a distance of 10 feet, after passing the pier. The packing of voids behind the laths with carefully rammed concrete, instead of spoil, gave a solid backing to the arch ring.

Both tunnels were completed in this manner up to the point at which the flat top construction was to be commenced, but there still remained a dumpling of rock and shale in the centre of each to be removed. These dumplings averaged about 10 feet in width and height. There was also the loose shale, and rock, which had been allowed to run down from the arch and to fill up what space was left in the headings after the brick walls were constructed. This material was taken out with compressed air pick machines, though there were places where it was sufficiently hard to necessitate blasting. Of course very light shots were fired so that no damage was done to the tunnel lining; indeed very little blas ing was done in any part of this tunnel. For a short distance it was the usual thing to shoot out the wall headings, but no blasting whatever was done in the arch excavations. Most of the spoil was picked out with the compressed air picks and these did the work splendidly, cutting out even the hard rock on the floor of the tunnels. The material surrounding the tunnels was left practically in its original state, no damage whatever was done to roads or buildings above, such as may have been occasioned by the concussion from blasting.

The Down City East tunnel was carried 610 feet from the station end and the Up City East about 535 feet in arch construction. Working from the Goulburn Street end with the same construction, some 90 feet were built of both tunnels. This left a length of 115 feet on the Up City and about 40 feet on the Down City tracks, passing under Mark Foy's building, and the structure which will eventually be erected on the Goulburn Street corner. It was therefore necessary to construct these sections of the twin tunnel with a flat top capable of sustaining the heavy loads from these buildings.

The walls of the tunnels were carried up to the required height and steel beams, 24 in. x $7\frac{1}{2}$ in., heavily plated, spaced 2 ft. apart, were placed in position, the roof was then poured, thus leaving the beams entirely encased in concrete. This portion of the work was constructed in open cut, a small section of the street being fenced off, to give sufficient room for the working of a crane, concrete mixer, etc.

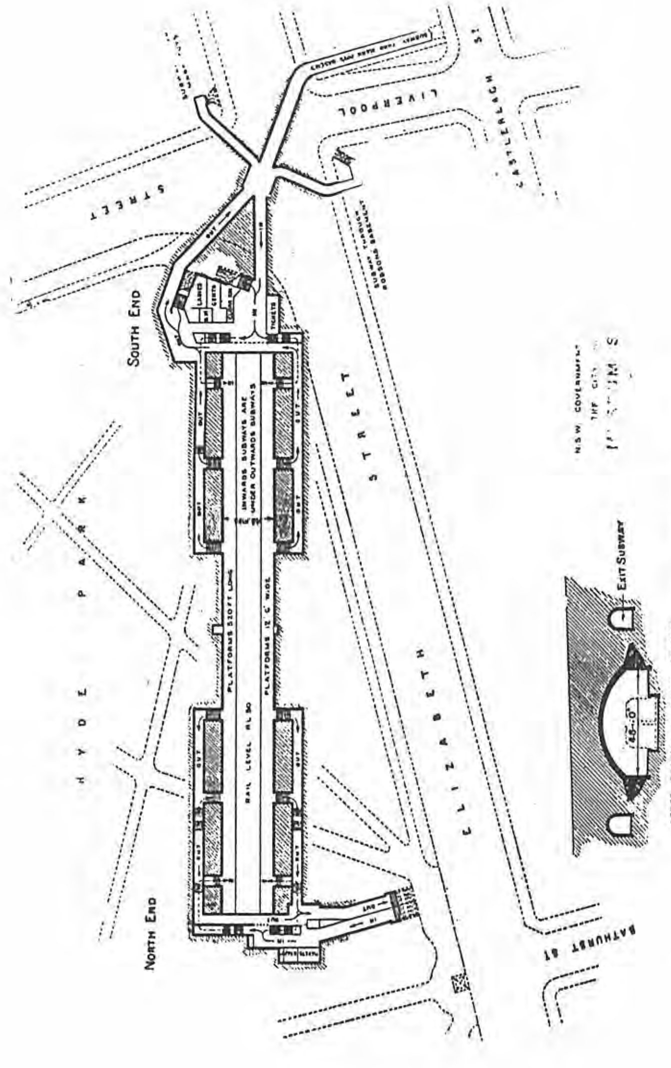


Fig. 20.—Museum Station.

Museum Station (Fig. 20).—Situated at the southern end of Hyde Park, this station is served by the two tracks, Down City East and Up City East, at a rail level of 50.00 ft., being 45 feet below the surface. As will be seen from the figure, the roof consists of a single reinforced concrete arch of 48 feet span, with a total length of 520 feet.

Platforms with a width of 12 ft. 6 in. on either side of the arch are served by 8 ft. wide longitudinal subways, located on the outsides of the main arch and leading to concourses at each end of the station. The main concourse is at the southern end, giving entrance and exit to the corner of Elizabeth and Liverpool Streets, while the smaller northern concourse serves Elizabeth Street at a point opposite Bathurst Street.

Separate ingress and egress subways, stairways and barriers are provided, the incoming passengers enter at either end of each platform, whilst the outgoing passengers have four openings, intermediately located, for exit.

At the southern end, in addition to the above entrances, a system of subways is provided giving communication to the station from the footpaths adjacent to the three buildings on the opposite sides of Elizabeth and Liverpool Streets, whilst the large 12-foot subway also gives direct connection to Mark Foy's Store. This arrangement will be of the greatest convenience to the public as the necessity for crossing the streets at surface level at this exceedingly busy corner is obviated.

In the design provision has been made for handling the largest number of passengers that the lines are capable of carrying. Concourses, passage ways, stairs, barriers and all offices have been therefore kept of ample proportions and designed for this maximum traffic.

The concourse construction is of steel beams encased in concrete. The southern concourse has columns spaced at 14 feet centres or less, of rolled steel joists set in concrete, having a total height from floor level to underside of roof of 14 ft. 6 in. The roof joists connecting the side walls are spaced 5 feet apart and support a reinforced concrete slab of varying thickness. Side wall columns being centered at 5 feet, are framed with channel bars and held to position by ¾ in. dia. tie rods, the concrete wall being finished to a thickness of 14 in. The subways have an inside width of 8 feet, with a clear height of 10 ft. 6 in. to the underside of the semi-circular roof. The walls and roof have a uniform thickness of 24 in. The main entrance and exit subways to the concourses are 10 feet wide,

with flat top construction and side walls of rolled steel joists set in concrete, having a thickness from 12 to 14 inches.

The rise from platform level to southern concourse is 17 ft. 4 in. and from concourse level to street 17 feet, making a total rise of some 34 ft. 4 in., while the northern end is somewhat greater, having a rise of 38 ft. 4 in. to the level of footpath in Elizabeth Street. The main arch with its span of 48 feet clear, and height above rail to underside of crown of 26 feet, is supported on abutments having an average width of

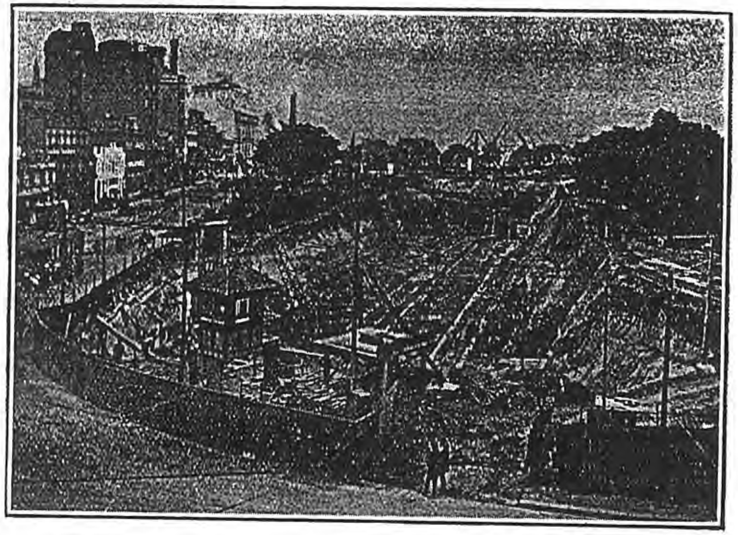


Fig. 21.—Museum Station—Excavation nearing Completion.

15 feet, with the springing line of the arch 14 feet above rail, giving a rise of 12 feet to the arch. The intrados of the arch is segmental to a radius of 30 feet, with the extrados set to a radius of 34 feet.

The thickness of the arch ring (Fig. 22) at the crown is 21 in., reinforced top and bottom with ¾ in. dia. bars at 9½ in. centres. The maximum compressive stress produced in the concrete at the crown, from the dead load was found to be 590 lbs. per square inch, which was increased some 60 lbs. per square inch by stresses due to a variation of 20° temperature and arch shortening, making the total stress in the concrete 650 lbs. per square inch.

The thickness of the arch ring at the haunches was 2 ft. 6 in. A construction joint was made between the abutment and the arch ring at a point 3 in. above the springing line of the arch, the joint being normal to the arch thrust. The maximum pressure on the abutment foundations, which are on poor sandstone, is 11 tons per square foot.

The "Bucyrus" dragline excavator which proved so efficient and economical on the other sections of the railway was unfortunately not available for the excavation of this station, which was carried out by navvies, supplemented by two steam shovels for a portion of the period. The total amount of excavation, including the subways, was 107,902 cubic yards. During the progress of the work, considerable quantities of shale and pottery clay were excavated and sold, also bands of red oxide of iron, which was used for colouring roofing tiles. A seam of coal, about ¼ in. thick, was also found.

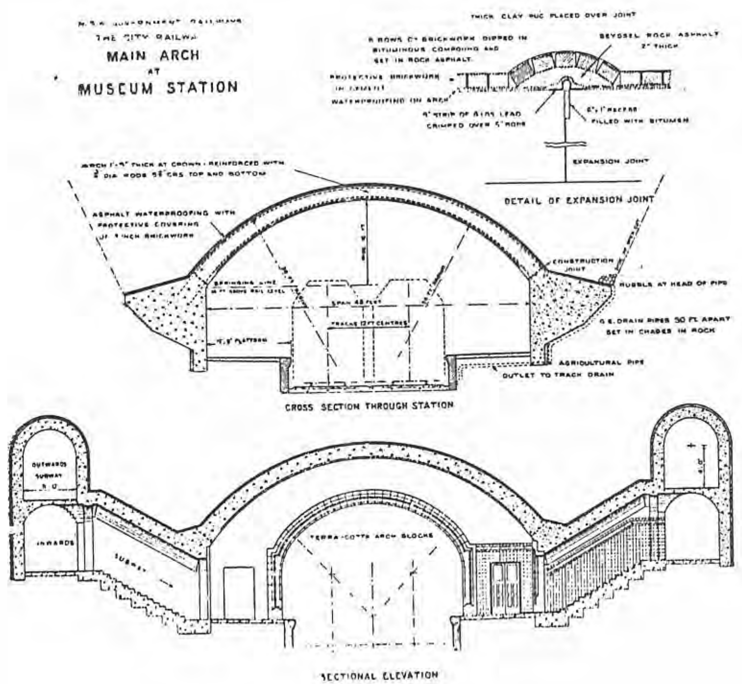


Fig. 22.—Main Arch at Museum Station.

Actual construction started with the concreting of the side walls and skewbacks for the arch, which were brought up to the level of the construction joint already referred to.

The falsework for supporting the arch was then erected and the reinforcement placed in position. The concrete was poured in sections of 30 feet per day, care being taken to ensure a good construction joint. The expansion of the arch ring was provided for by the placing, at intervals, of expansion joints, a detail of which is shown on Fig. 22. Six of these joints were placed in the total length of the station, at distances of 76 ft. 8 in. to 137 ft. 8 in. and have given entire satisfaction.

The whole of the roof is waterproofed with a layer of asphalt, ¾ in. thick, and protected with bricks laid in cement mortar. The earth filling was then placed in position and the surface of the park restored. The waterproofing of the subways and concourses was also carried out in the same manner. Both concourses have installed a complete system of ventilation, which ensures a change of atmosphere every 10 minutes in the concourse and offices and every 5 minutes in the lavatories.

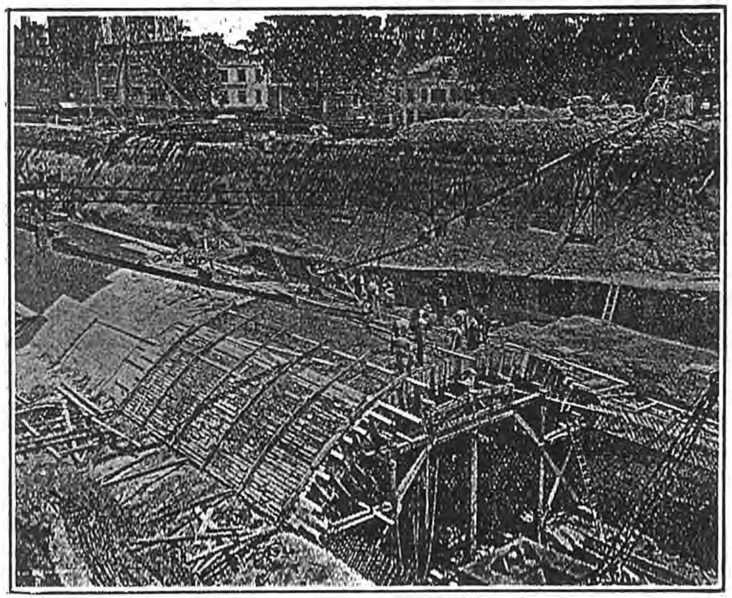


Fig. 23.—Museum Station—Pouring Concrete in Main Arch.

The drainage scheme for the station provides for the drainage of subways and batteryroom as well as the sewerage from the lavatory block, the whole of which after concentrating in a main shaft on the south side of the principal entrance stairway, is diverted by a 6 in. pipe (in tunnel) to the main Bondi sewer in Liverpool Street. Provision has been made throughout for the trapping off from the sewers, all the flushing and floor drainage branches, and a number of inspection chambers has been provided at the junction and bends, for the efficient cleaning out of pipes in case of blockage.

The construction of the passenger subways, across Elizabeth and Liverpool Streets, at the southern end of the station, involved a considerable amount of alteration to the existing sewers, water supply mains and telephone tunnel in Liverpool Street.

A new 18 in. water main along Liverpool Street to connect with the existing mains had been authorised by the Metropolitan Water, Sewerage and Drainage Board, which, if carried out would have interfered seriously with the construction of the subways. It was therefore decided to divert the pipe from a point in Liverpool Street near Commonwealth Street across Hyde Park to Bathurst Street to intersecting points at Elizabeth, Castlereagh and Pitt Streets. This work was carried out by the Metropolitan Water, Sewerage and Drainage Board.

A 16 in. pipe sewer from Bathurst Street to Hay Street sewer, with a depth below surface level of 10 ft. 6 in., was also an obstacle to the construction of the two western branches of the subway. It was therefore decided to cut out a section of this sewer between the limits of subway construction and to divert the portion between Bathurst Street and the north side of Liverpool Street into the main Bondi sewer.

The telephone tunnel, which is situated under the southern footpath of Liverpool Street, presented a still greater difficulty. The tunnel which is 5 ft. 10 in. high, has a clear width inside of 4 ft. 6 in.; the walls and semicircular roof are in 9 in. brickwork, over a 12 in. concrete floor.

It is the main trunk for the telephone cables to the whole of the eastern suburbs. The tunnel clears the Up and Down City East structures, but runs transversely across the line of passenger subways leading to the southern side of Liverpool Street. A plan was prepared and the work duly carried out, which entailed the underpinning and deepening of the old tunnel, without interfering with the telephone services during the construction, and yet at the same time provided for the maximum amount of headroom under the passenger subways.

The existing 9 in. drain immediately under the floor of the telephone tunnel, between the limits of reconstruction, was removed, and at a point on the northern end of the tunnel, was diverted by a 9 in. pipe into an existing manhole on the eastern side of Elizabeth Street near the intersection of Clark Street.

Tunnels between Museum and St. James Stations (Figs. 24 and 25).—The Down City and Up City East tracks leave the Museum station to enter a double track tunnel 27 feet wide, which branches into two single line tunnels at a point 228 ft. 5 in. from the northern end of Museum station. The Down City East tunnel on the eastern side descends on a grade of 1 in 150 to pass under the two Eastern Suburbs tracks at a point adjacent to Park Street and thence on a rising grade of 1 in 56 to St. James Station, with a total length between ends of stations of 21 chains 22.66 feet.

The Up City East tunnel on the western side has a rising grade of 1 in 180 and a length of 20 chains 55.71 feet.

The two Eastern Suburbs tracks enter St. James station in a double track tunnel between the Down City and Up City East tunnels. This double track tunnel has a clear width of 31 feet for a distance of 102 feet from the station end; at this juncture a twin tunnel construction takes the two tracks on a rising grade of 1 in 40 to fly-over the Down City East track under the park as shown on Fig. 24.

The Down City East tunnel has a cross-over connection to the Down Eastern Suburbs track at the junction of the twin tunnels (Eastern Suburbs) to the double track tunnel.

The cross sections of the tunnels and fly-over are shown on Fig. 25.

The double track tunnel from the Museum station was constructed to the bifurcation of the Down and Up City East tracks, by tunnelling and the Down City East from this point to the south side of Park Street, with some 200 feet of the Up City track, was carried out in open cut. Very bad ground was encountered in the heading of the double track tunnel, that is to say, a soft roof mainly composed of shale and a very hard rock bottom. The roof from the springing line of the arch upwards had to be close timbered to keep it from falling in, and there was always a danger of the timber being displaced when blasting the rock in the bottom portion. Special care was taken in blasting. Horseheads of 14 ins. × 14 in. ironbark, 34 feet long were used, being held in hitches at either end and there were four

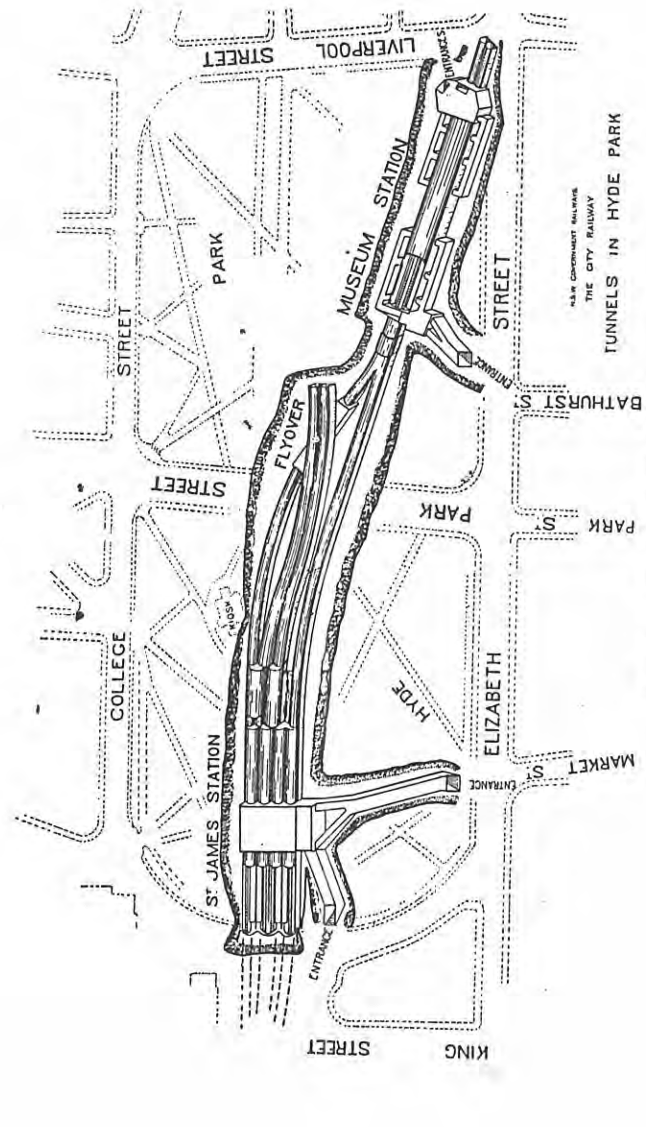


Fig. 24.—Tunnels in Hyde Park.

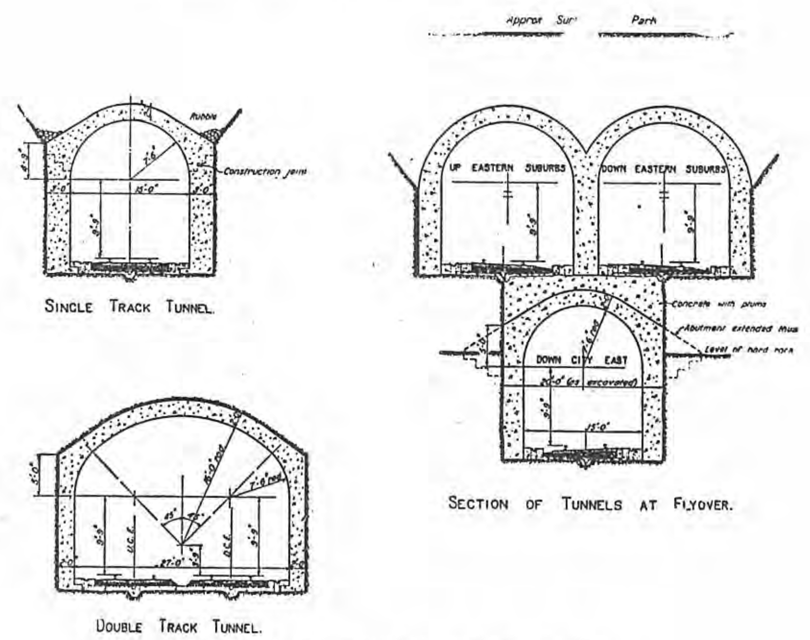


Fig. 25.—Tunnel Sections in Hyde Park.

round hardwood logs of about 12 in. diameter under each horsehead. The spacing of the horseheads was 8 ft. 3 in. centres, while the greatest spacing between the legs was 11 feet. The load on the timber was so great that some of the 14 in. × 14 in. horseheads had as much as 5 in. of sag in them and scm: of the ironbark crownbars had even more than this. The amount of excavation in this section was upwards of some 3,500 cubic yards.

The side walls and arched roof of the tunnel were concreted to a minimum thickness of 24 in. The concrete was mixed at a high level and delivered by chute to the 6 in. holes drilled from the surface. This method of pouring is explained in the description of the single tunnels given later.

In concreting the arch of a timbered tunnel, it is usually necessary to leave the crownbars and all the timber above them in place and to pack the concrete firmly around them. Allowance is always made for this when taking out the excavation and the timber is so placed as to allow for the full thickness of concrete beneath it. This margin is kept about 3 in. on

the full side, so that if the bars do happen to sag a little the arch still has its full complement of concrete underneath them.

The single track tunnels constructed in open cut had a clear width of 15 feet, with a height of 9 ft. 9 in. to the springing line of the arch, which is semicircular to a radius of 7 ft. 6 in. The construction of these tunnels was continued on the northern side of Park Street. Two 15 ft. diam. shafts were sunk, one on the Down City line about 115 feet from Park Street and the other on the Up City line some 40 feet from the street. Headings were then driven in both directions from the shafts in the two tunnels; the ground in the Up City tunnel was exceedingly bad and very heavy timbering had to be used.

The concreting of these tunnels was carried out by means of a concrete mixer equipped with steel chuting, from which the concrete was poured down 6-inch holes drilled through from the surface by a Southern Cross boring machine using a 6 in. bit. These holes were drilled always one in every 16 ft. 6 in. length, which is the length of arch work put in at one pouring. As a result of this method of pouring the concrete there was practically no interference with the excavating work proceeding in the tunnels.

The twin tunnel construction for the Eastern Suburbs railway was executed in open cut, excepting the small section under Park Street where it was decided to drive the twin tunnels using the same methods as were employed at the southern end of Museum station. First of all three bottom headings were driven on the line of the three walls of the tunnels. The centre one was some 13 ft. high by 4 ft. wide and the outside ones the same width but only 10 ft. 6 in. high from rail level. The headings were timbered by means of squared sets, using 8in. x 5 in. sleepers for caps and 8 in. x 5 in. hardwood legs, being close lathed on the roof and sides. They were driven to their full length of approximately 90 feet, when the bricklayers were brought on the job, and, starting at the extreme ends, built the three walls of the tunnels. The side walls were made 3 ft. thick and finished at the springing line of the tunnel arches (9 ft. 9 in. above rail level). The centre wall was 2 ft. 8 in. thick and was carried up 2 ft. 3 in. above springing line, thus giving an overhang of 3 in. on each side at the top of the wall. When the 90 ft. length of these walls had been completed, the excavation of the arched portion of the tunnels was commenced.

To carry the overburden on this section during construction, instead of the usual timbering, the method of building

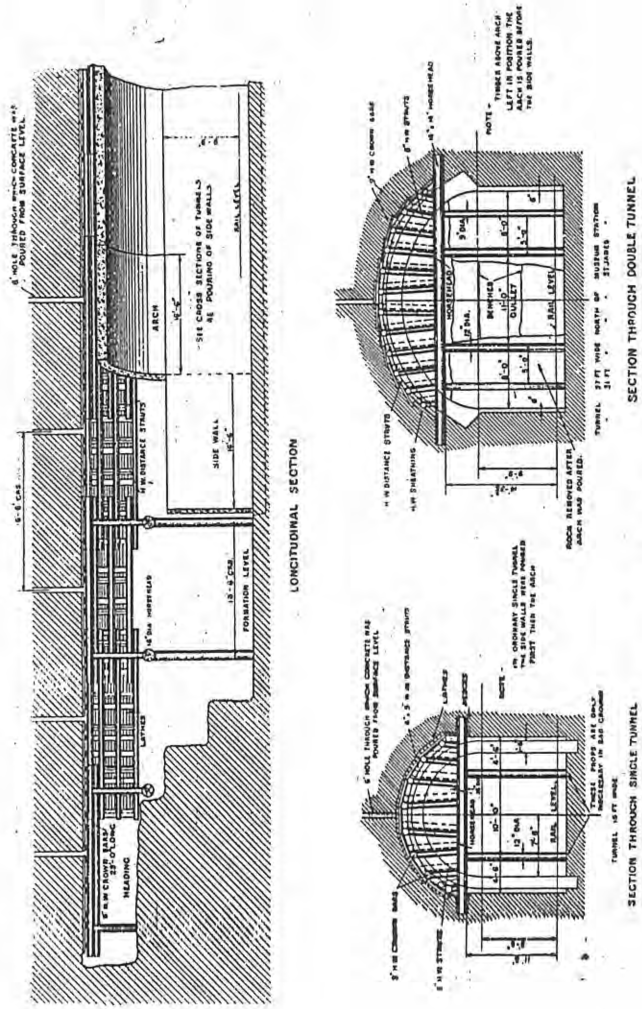


Fig. 26.—Methods of Tunnel Construction.

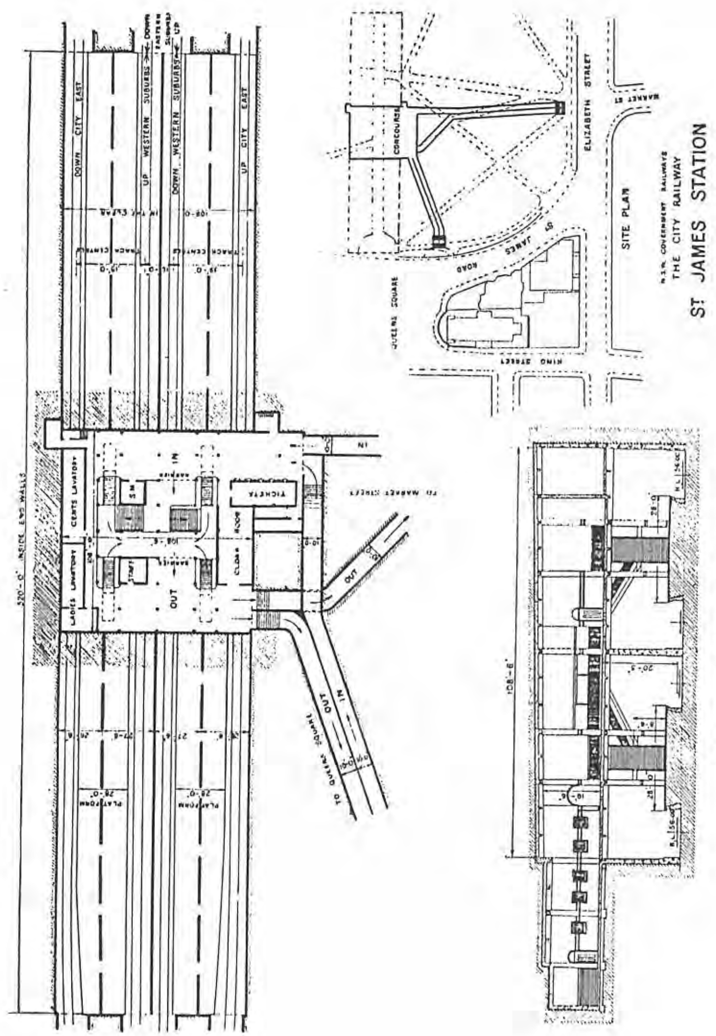


Fig. 27.—St. James Station.

the arch was precisely the same as that employed in the tunnels from the southern end of Museum station to Goulburn Street for the arched tunnels.

The drainage of the Down and Up City East tunnels between Museum station and St. James station and the Eastern Suburbs tunnels to Park Street from St. James station, is connected to the Bondi sewer crossing under Hyde Park at a low level. However, in constructing the Up and Down City East tracks, the tunnels ran through the line of a 6 in. pipe sewer leading from the City Council's underground lavatory in Hyde Park near the intersection of Park and Elizabeth Streets. A new manhole was constructed on the west side of track tunnels, and the 6 in. pipe intercepted and diverted under rail level to the existing manhole on the eastern side and thence to the Bondi sewer.

St. James Station (Fig. 27).—This station is located at the northern end of Hyde Park, with entrances and exits from Elizabeth Street opposite Market Street, also from St. James Road in Queen's Square at the top of King Street.

With a rail level of 56.00 the station is some 40 feet below the surface of the park.

The two island platforms are served by four tracks, the Down City and Up City East lines occupying the outside roads, while the two inside tracks serve the eastern suburbs.

The outside walls of the station at platform level are 108 feet apart, the roof being supported by four 25 ft. 6 in. reinforced concrete arch spans, carried on reinforced concrete walls of 24 in. thickness. The construction with the leading dimensions of these arches, centre and side walls is clearly shown on Fig. 28.

The two island platforms have a width of 28 feet with an overall length of 520 feet and are served by stairways to the concourse.

One 12 ft. stairway from the concourse to each platform gives access for the incoming passengers, while two 6 ft. stairways on each platform carry the outgoing passengers to the concourse floor, a rise of 16 ft. 6 in.

The concourse situated in the centre of the station, has a total width of 108 ft. 6 in. and a length of 108 ft. 6 in., with a clear height from floor to roof panel of 16 to 18 feet, and is constructed with steel columns and girders encased in concrete, with reinforced concrete floor and roof panels.

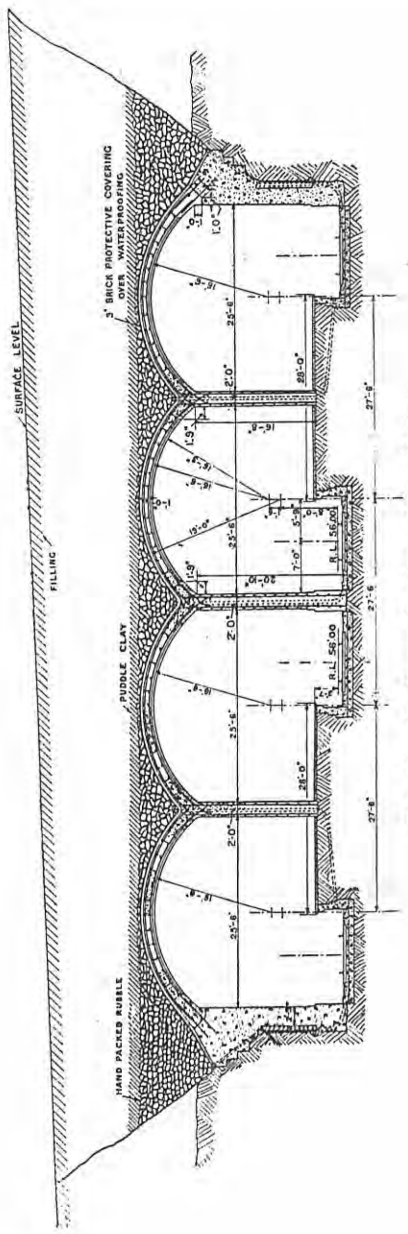


Fig. 28.—St. James Station. Cross Section.

Separate entrance and exit subways are provided so that the incoming and outgoing passengers do not meet and thus avoid that mutual interference which a common entrance and exit would undoubtedly have. The subways are in twin construction, with plain concrete walls and reinforced concrete roof, with a clear width of 10 ft. to each subway and a height of 7 ft. 10 in. to the springing line of the low sprung arch, which has a thickness of 12 in.; the subways lead to an easy flight of steps giving access to the street.

The total rise from platform level to the St. James Road entrance is 36 ft. and that to the Elizabeth Street entrance 17 ft. 6 in.

This station is designed to serve terminating, as well as through traffic, being the junction station for the Eastern Suburbs connection, and provision has been made, as in all stations, for handling the maximum number of passengers that is ever thought likely to be realised.

The four main arches spanning the station have a height from rail level to underside of crown of arch of 25 ft. 9 in. and support something like 14 feet of fill. The arch has a thickness of 14 in. at the crown and 21 in. at the haunches, with $\frac{3}{4}$ in. diameter main reinforcement bars at 12 in. centres top and bottom. The distributing bars placed longitudinally are $\frac{3}{4}$ in. diameter and spaced 24 in. apart on both the intrados and extrados.

The structure was designed as a series of arches over elastic piers and the following maximum stresses were obtained. At the crown of the arch the maximum compressive stress was 240 lbs. per sq. inch, while at the foot of the pier the stress did not exceed 280 lbs.

In the open cut excavation for the station, a "Bucyrus" dragline excavator, with two steam navvies was employed, while a three-ton electric crane was installed in the cut to deal with the larger pieces of rock. The total quantity of spoil excavated amounted to 128,446 cubic yards, consisting principally of shale and rock. It is interesting to note that the "Bucyrus" dragline removed in 26 consecutive working days (8-hour) a total of 26,000 cubic yards of material.

Construction started with the pouring of the side walls, which were at once waterproofed with asphalt and backed with 9 in. brickwork. At the top, the walls were stepped back into the rock face to form the abutments for the side arches. Both side walls have a 4 in. drain at the base, while under the

hand-packed rubble over the haunches of all the arches a similar pipe is lead down the walls and piers to the track drains, thus a perfectly dry roof is assured.

Where the floor of the concourse abuts on the arches, an expansion joint is provided over the full width of the station, thus leaving the concourse floor quite free from the side walls of the concourse and end walls of the arches.

The centre walls were then poured and the timber centering for a length of 30 feet erected. The placing of the concrete in the arches then proceeded in the same manner as described in the building of the Museum station.

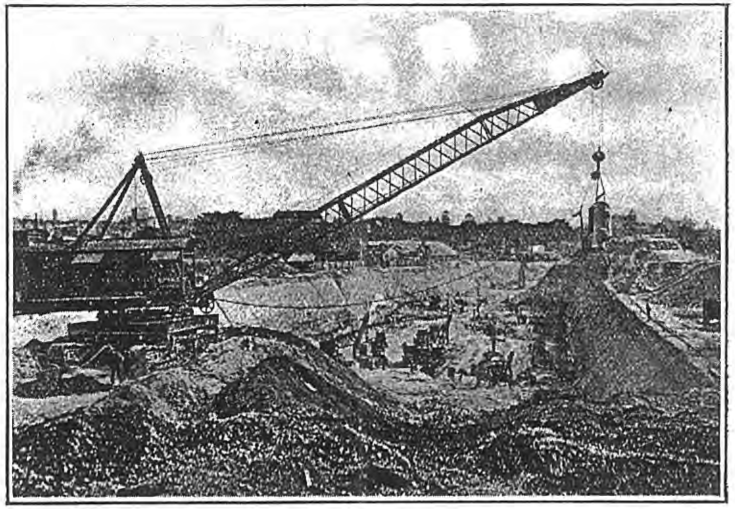


Fig. 29.—Dragline Excavator at St. James Station Site.

All outer walls, the main arches, roofs of the concourse and subways are completely waterproofed with a layer of ¾ inch mastic asphalt, this covering in turn being protected by a layer of brickwork in cement mortar.

A complete system of ventilation has been installed in the concourse, lavatories and all offices. Air ducts are so arranged that a complete change of atmosphere is provided every 10 minutes in the concourse and offices, and at intervals of 5 minutes duration in the lavatories.

A fairly elaborate system of drainage had to be provided at this station, for dealing with the lavatories, concourse and subways.

The whole of the lavatory drainage had to be carried through the eastern wall of the station to a manhole, and on account of the difference between the pipe invert and top surface level, it was necessary to construct a special pipe inspection chamber on the outside of the eastern wall, running practically the whole length of the concourse. Entrance to the chamber is effected through a door in the attendant's room.

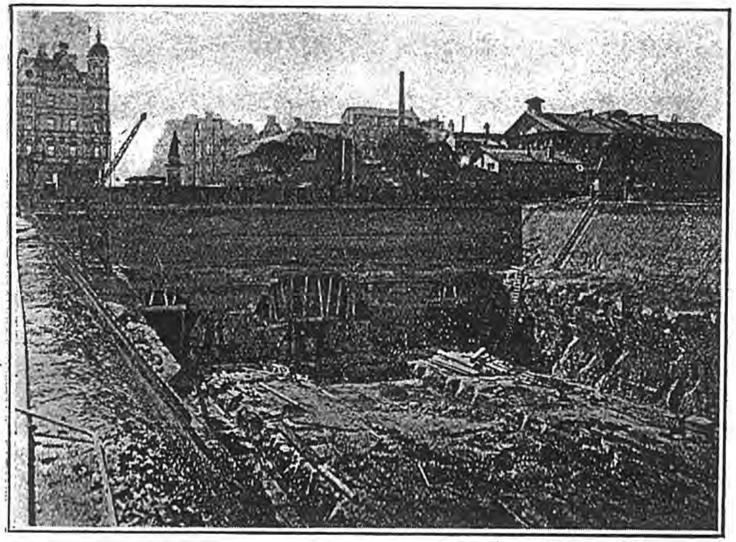


Fig. 30.—Open Cut for St. James Station, looking North. Showing Tunnels under Macquarie Srteet.

The branch pipes in this chamber are all fitted with inspection caps, and in case of chokage, are easily accessible for cleaning. The drainage from the manhole situated in the centre of the chamber is carried down a shaft to a convenient distance under the tracks, to a second manhole built outside the western wall of the station. Between these two manholes, and in the line of pipes, a smaller inspection manhole was constructed on the Up Western platform, intercepting at this point the drainage from the signal box at the southern end of the platform and also the whole of the concourse drainage. The track drainage and seepage throughout the station limits is

collected by a 6 in. track cross drain near the centre line of the station and diverted to the western manhole through a trap to the main sewer. The main 6 in. sewer then follows a western direction to a manhole outside the south wall of the passenger subways near Market Street and at this point it intercepts the whole of the subway drainage discharging it into the Harrington Street branch of the Bondi sewer. The drainage of the passenger subways is well provided for by a complete system of 4 in. bends and cast iron slot drains near the side walls.

Every facility has been provided for the complete inspection and cleaning of all pipes and fittings.

Station Fittings and Finish.—The three stations described, namely Central, Museum and St. James, are furnished with a modern system of train indicators, placed in suitable positions so that travellers may see at a glance the time and number of platform from which their train departs. The indicators show the three approaching trains in the order of their arrival. At the departure of the first train, the indicator will change number two to number one and the destination of a third train appears. This system of train information combined with the one-way

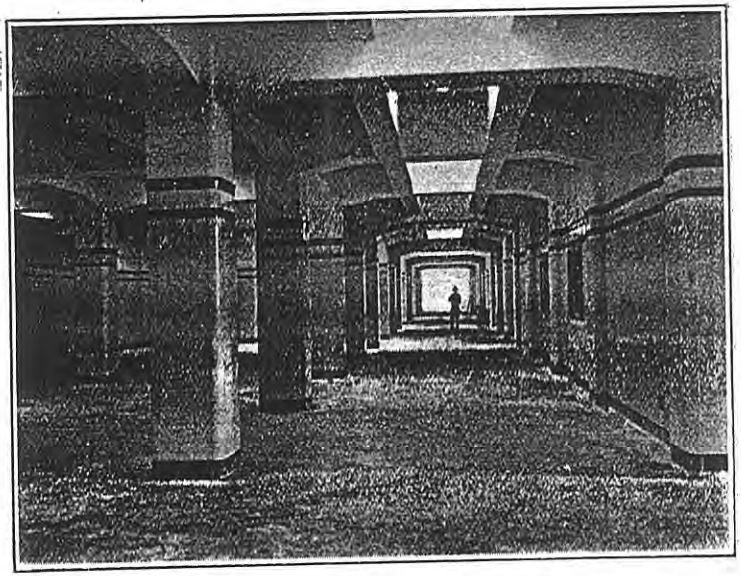


Fig. 31.—*Northern Concourse, Central Station.*

traffic arrangements at all stations should prevent traffic congestion and provide free movement for the passengers.

The interior walls of the stations and subways are finished with a hard glazed tile to a height of 8 feet or thereabouts. Above this the concrete is treated with two coats of mill white water paint sprayed on, giving a hard white surface which is also continued over the ceilings.

The cream body tiles with top and bottom moulding courses are common to all stations, but the colour of the moulding tiles will be different at the various stations, which should assist the passengers in a rapid realization of their location. The colours chosen for the Museum and St. James stations are red and green respectively, while the Central station concourse, which is not observable from the trains, is also decorated with the green tile moulding. The lavatory walls, in Museum station only, are entirely covered with white glazed tiles, with neutral tint mouldings.

The concrete floors of the concourses and subways are covered with a continuous layer of mastic asphalt, $1\frac{1}{4}$ in. thick, having the following composition :—

Natural Neuchatel Rock Asphalte	50%
Bluestone Chippings	25%
Fine Bluestone Screenings	10%
Trinidad Bitumen	15%

The lavatory floors are covered with Terrazzo paving, light grey in colour and having a finished thickness of $\frac{3}{4}$ in. after grinding. Waiting rooms and station offices have a floor surface of Magnesium composition, some $\frac{3}{4}$ in. thick, of a light brown colour and pleasing appearance.

To ensure a non-slip, long-wearing tread for the stairways, a mixture of carborundum, sharp sand, and cement, in the proportion of one, one, two, was laid over all treads and landings to a thickness of $\frac{3}{4}$ in. All steps have a 12in. tread with a 6 in. rise, while the extreme height between floor and landing, or the rise of any one flight of steps, never exceeds 8 ft. 6 in.

The platforms at Central station have a floor covering of tarred metal, well rolled and worked to a smooth surface while the platforms in the Museum and St. James stations, being under cover, are finished with the bituminous asphalt, $1\frac{1}{4}$ in. thick, already referred to as the floor covering for the concourses.

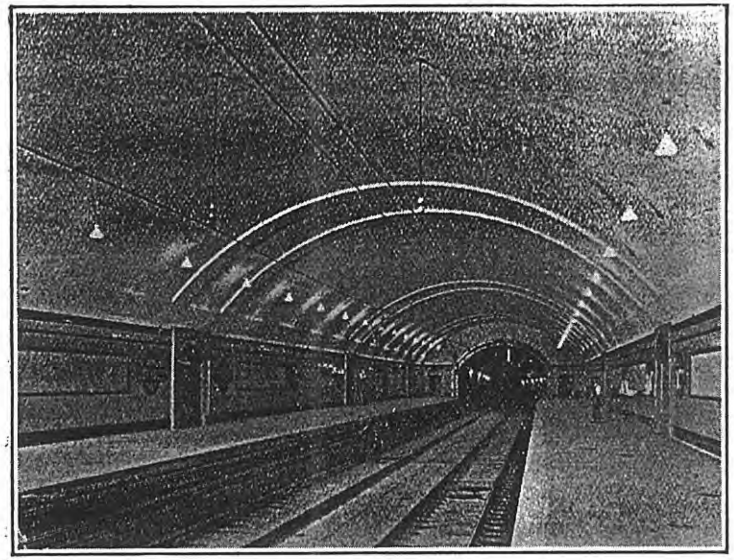


Fig. 32.—*Museum Station.*

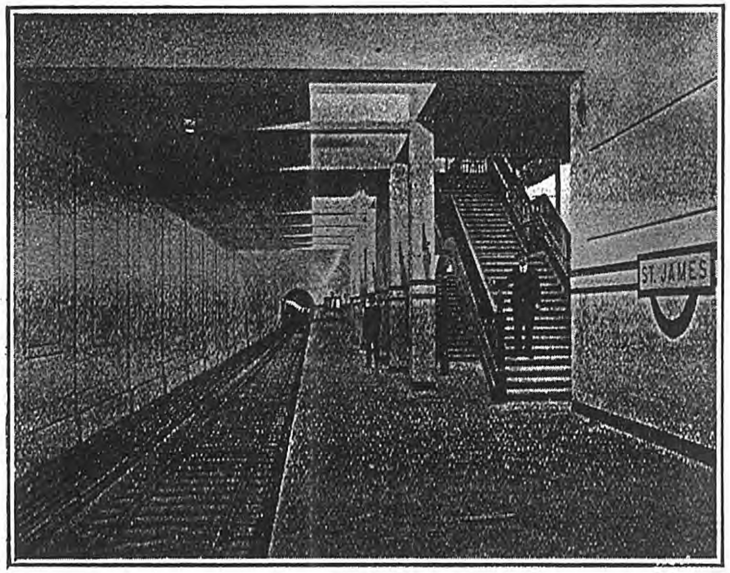


Fig. 33.—*St. James Station.*

The wrought iron work enclosing the stair-wells on the platforms at Central station is of simple design, the balustrade rising 4 ft. 6 in. above the platform level, the main uprights being cemented into and stayed from a concrete kerb round the wells. Square newels of cast iron are placed at the head of the stairs, with a collapsible gate between them. The entrance barriers are placed at the concourse level and consist of cast iron posts and collapsible gates with short sections of wrought iron balustrading between, of the same design as that used for the stair wells. The exit barriers consist of posts and gates only.

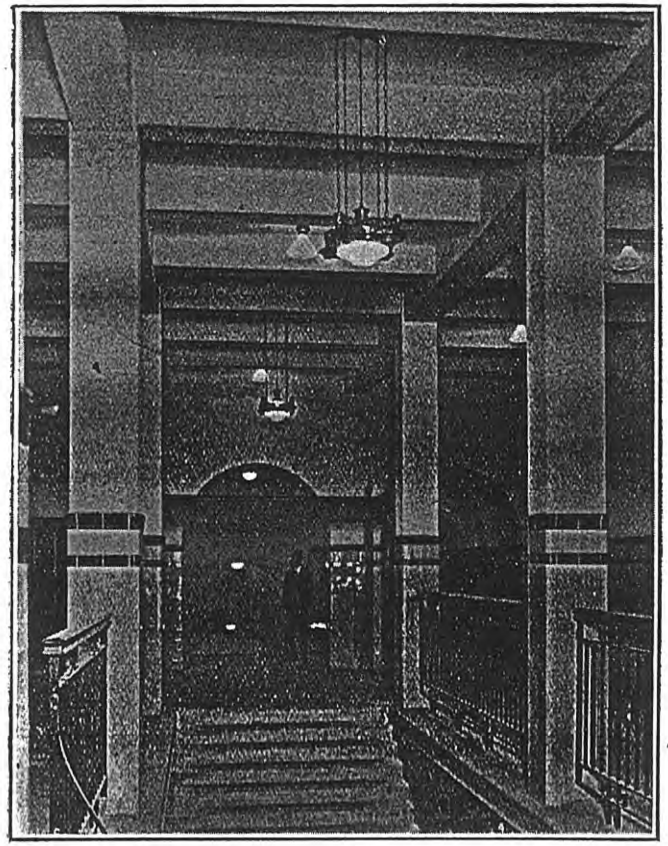


Fig. 34.—*Northern Concourse, Museum Station.*

The handrailing at the sides of the stairs is formed of 2 in. diam. oxidised brass piping with cast bronze brackets fixed to the tiled walls.

At the north and south concourses of Museum station, barriers are used similar to those mentioned above, but the design of the balustrading is somewhat different, the ornament being supplied by the introduction at intervals of a Greek fret pattern. The handrailing is the same as at Central station, there being a total of almost 1,200 lineal feet in these two concourses.

St. James station with its open stair arrangement has called for extensive balustrading which has been carried out in wrought ironwork of plain bars with panels at intervals of a geometric pattern, furnished with a base of sheet iron. The handrail is bracketed from the balustrade and as a finish to the latter, which is 4 feet high, there is a capping of extruded brass. Over 800 feet of this capping was used and greatly enhances the appearance of the ironwork. Entrance and exit barriers consist of cast iron posts with Doric caps and bases, collapsible gates and short sections of wrought iron balustrading to link up with that around the stair wells.

The station offices have been designed to give the maximum convenience to the travelling public and the appurtenances are of the most modern character. Telephone facilities are provided throughout for the general public, as well as the railway staff.

The lighting of the stations is so arranged that a failure of two separate sources of supply is necessary to effect a complete shut down in the lighting; these sources are represented by high tension ring mains traversing the system and feeding the lighting reticulation through two independent transformers; while a constant supply of 10% from a 25-cycle main, would give sufficient light to the stations in case of failure of the main supply.

A complete water supply system has been installed throughout all stations. In addition to the ordinary supply for the lavatory blocks in each station, provision has been made for hosing down all concourses, subways and platforms, besides fixing drinking fountains in the most suitable locations.

In the selection of size of pipes a fairly wide margin has been allowed, so that there may be no depletion of supply due to the encrustation of the pipes in the future, also wherever possible more than one main supply has been availed of and

the schemes so arranged that in case of a breakdown in any one main there will be no interruption to the station supply.

Tunnels North of St. James Station (Figs. 26, 30 and 36).—The location of these tunnels is shown on Fig. 3.

The two City East tracks are situated on the extreme sides of St. James station, with the Eastern Suburbs tracks, which have now become the Western Suburbs Up and Down Lines, between. A cross-over is provided from both the City lines to the adjacent Western Suburbs tracks, which also have a crossing, thus enabling a change over between the Down City and Up City trains.

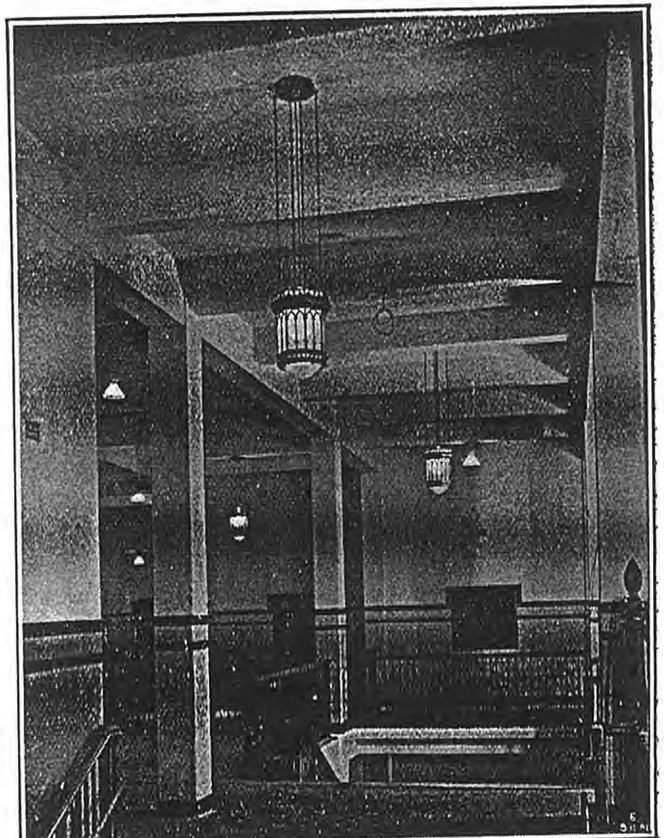


Fig. 35.—Concourse, St. James Station.

The double track tunnel accommodating the Western Suburbs lines is carried some 270 feet from the north end of St. James station under Macquarie Street, before bifurcating and joining the City East tracks. This junction occupies about 300 feet of special tunnel work before the two western tracks are brought together again in a double track tunnel and proceed towards the western loop.

The Down City East and Up City East tracks leave St. James station in single track tunnels and almost immediately connect up with the above mentioned special work, which once

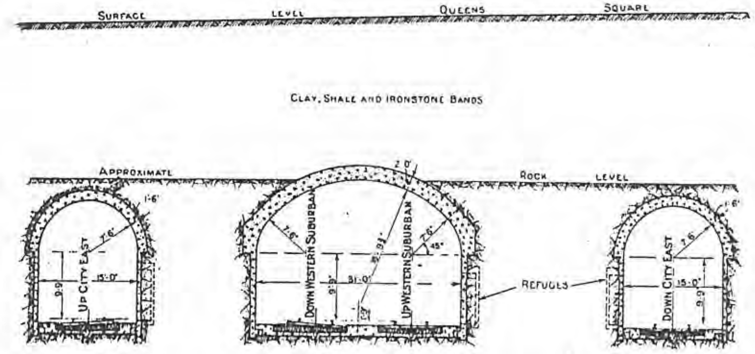


Fig. 36.—*Tunnel Sections, North of St. James Station.*

passed they continue on the outside of the double track western tunnel until the latter passes under the Up City track; they then proceed in the loop under the Botanical Gardens to come together finally in a double track tunnel just before reaching Macquarie Street, when they debouch on to a viaduct leading to Circular Quay station.

The three tunnels leaving the station cutting, started in fairly good rock and not a great deal of timbering was required, but the quality of the rock soon changed and very close timbering had to be resorted to.

The method of driving this double track tunnel was slightly different from that employed through Hyde Park where soft shale was mainly encountered; here however the tunnel was driven through fairly hard sandstone, though soft bands were constantly met with. The lay of the sandstone beds was quite unusual and clearly defined free beds in the sandstone were lying at an angle of about 10 degrees off the vertical, sometimes only 12 in. apart, and running nearly in the same direction

as the tunnel, also the usual horizontal beds, so that the stone was more or less loose irregular blocks.

This necessitated a very close timbering of the roof, and to avoid the possibility of displacing the timber, while blasting out the bottom portion, the rock below the springing line being sufficiently strong to carry the weight, skewbacks were cut in the rock and the concrete arch poured on to these before the lower portion of the tunnel was excavated. The method of driving and timbering the arch was similar to that already described, except that no square sets were used in the heading and fewer lathes needed over the crownbars. In order to form a narrow gullet in the tunnel centre for bringing the spoil waggons up to the face and to avoid knocking any of the timber out, a bottom heading some 10 feet in width and 6 feet high was driven. This heading was maintained about the same distance from the bench as the top heading, with a rock thickness of 7 ft. between the two headings. The top segment of the arch was taken out to the floor level of the top heading and the crownbars placed and supported on short ground legs. The horsehead at the back end of the bars was level with the roof of the bottom heading and supported by the benches on either side, thus leaving a vertical face of rock 7 feet high practically hard up against the horsehead. On account of the horsehead being kept so low down, the legs supporting the bars were 12 feet in length and great care had to be exercised to avoid knocking them out. The usual method of removing the rock was adopted, first shooting the top portion of the bench up and then the bottom portion down into the lower heading, thus very little danger existed of big stones being thrown against the legs on the horseheads.

The concreting of the arch proceeded continuously and at almost the same rate as the driving, being kept as close as possible to the working face of the tunnel and never more than one chain behind it. The concrete was poured through 6 in. holes bored from the road surface along the centre line of the tunnel and spaced 16½ feet apart.

The work of removing the side benches was then proceeded with. Starting on one side of the tunnel close drilling and shooting carried the rock face some 6 in. behind the finished line; thus leaving room for a 6 in. facing of concrete on the sidewalls of the tunnel. Had the rock been sound and free from vertical faults this concrete facing could have been dispensed with, but, owing to the frequent faults and bands of soft rock, there was always the possibility that portions would

become loose through the vibration and fall out, it was therefore necessary to face the side walls with concrete.

The ventilation of the tunnels received careful attention, for if tunnels are not well ventilated where heavy blasting is necessary, the men are not able to go back to the working face for some considerable time after shots have been fired. This of course adds to the length of time required for the excavation, to say nothing of the increased cost. A satisfactory and efficient system was installed for rapidly exhausting the foul air and smoke out of the tunnels during the construction. Six-inch diameter holes were bored from the street surface to the level of the tunnel arch for ventilating and later for pouring the concrete. These holes were bored in advance of the driving at 16½ feet centres. Four fans, each with a capacity of 1,000 cubic feet of air per minute, were installed in the street above and were constantly in service, the back one being moved ahead each time a fresh hole was met with as the heading advanced below. The fans drew the air from the top of the tunnel and created a good draught of fresh air right from the mouth. The smoke from the fuses and gelignite rise to the roof of the tunnel, and by the exhaust draught of the fans, within five minutes after firing up to 50 shots, the tunnel was clear of smoke and fumes.

Investigations of condition of air in these tunnels gave the following results :

TABLE I.

Tunnel.	Time.	Particles of Silica Dust per c.c. of Air	
		Below 2 Microns.	Between 2 and 10 Microns.
East Tunnel:			
Heading on eastside, 460 ft. from Station. Suction hole to surface 25 ft. from mouth, one hour after firing.	11.15 a.m.	200	4
Heading being cut to meet the centre tunnel. 240 ft. from station. Four men boodling, natural ventilation.	11.40 a.m. 11.50 a.m.	168 156	nil 8

TABLE I.—(*Continued*).

Tunnel.	Time.	Particles of Silica Dust per c.c. of Air	
		Below 2 Microns.	Between 2 and 10 Microns.
East Tunnel—(Continued).			
13 shots were fired in the heading at 12.43 p.m. Roots Blower was blowing air along the tunnel. The men returned and sample was taken at	12.50 p.m. 12.55 p.m.	1644 456	24 nil
Heading on east side where first sample was taken, suction hole to surface. 9 shots were fired at 2.10 p.m. Men returned and sample was taken at 2.15. The heading was very thick with dust.	2.15 p.m. 2.20 p.m. 2.25 p.m. 2.30 p.m. 2.35 p.m. 2.45 p.m.	over 10,000 " 5,000 4500 2500 1100 204	 100 100 36 6
Sample taken from in front of man holding moil, working on wall, from bank 10 ft. high.	11.10 a.m. 11.25 a.m.	250 258	4 4
60 shots were fired at 2.25 a.m. Roots Blower was operated for 10 minutes. The men did not return but left at the end of the shift at 2.45.			
A sample was taken at floor level, at	2.45 a.m.	180	18
8 men commenced work in heading and sample was taken at	3.5 a.m.	210	5
Sample from floor level	3.10 a.m.	173	nil
Centre Tunnel:			
Sample taken from in front of man spalling with air pick, 200 ft. from station. Hard rock	1.40 a.m. 1.50 a.m. 3.0 a.m. 3.10 a.m.	156 252 90 155	nil 6 nil 1
Bank 10 ft. high, 200 ft. from station. Samples taken in front of man using air pick to cut hitch 10 in. x 10 in. by 15 in. 3 ft. above the floor, samples taken	12.30 p.m. 12.35 p.m. 12.37 p.m.	240 222 270	— — —

TABLE I.—(*Continued*).

Tunnel.	Time.	Particles of Silica Dust per c.c. of Air	
		Below 2 Microns.	Between 2 and 10 Microns.
West Tunnel:			
Mouth, 300 ft. from station. 14 shots fired on open bank 80 ft. from mouth of tunnel at 12.10 p.m. Ventilation was by means of the suction holes in the heading 120 ft. farther in.	12.10 p.m.		
The men resumed at 12.20 p.m.	12.20 p.m.		
Boodling—8 men on floor Jackhammers—one at wall Air picks—one scabbling wall one spalling on floor			
Sample from front of man boodling.	12.20 p.m.	210	4
Front of man spalling with air pick.	12.35 p.m.	100	2
Front of man scabbling wall with air pick.	12.45 p.m.	168	12
	,,	130	nil
	,,	100	nil
Front of man boodling on floor.	12.50 p.m.	60	2
Two air picks were used to cut the foundations for the west wall, one man was working in a hard patch of stone, the other in much softer material.			
Front of man in very hard stone	1.35 p.m.	650	nil
,, ,, softer stone	,,	290	4
,, ,, boodling in tunnel	,,	113	nil
,, ,, hard stone	,,	384	nil
,, ,, hard stone	,,	504	6
,, ,, softer stone	1.45 p.m.	80	nil
,, ,, softer stone	,,	60	nil

These results show that the continual suction of the air from the headings improves the condition of the air, so that 15 minutes after firing the dust content is generally well below the 200 particles per c.c. limit fixed, and the men can return without any discomfort.

The track drainage and seepage of the tunnels from the north end of St. James station are intercepted at the lowest point of the ease on the Down City East track, the western suburban tracks and the Up City East track-drains being connected to the down City track drain at convenient points. A 9 in. pipe from the last mentioned track connects to an 18 in. pipe in the Botanical Gardens, which in turn will discharge into Farm Cove.

Concrete.—With concrete as the principal building material used in the construction of the City Railway, both in the form of mass concrete and reinforced concrete, a series of tests was made prior to the commencement of concreting to verify results obtained in America with regard to the quantity of water, the effect of rodding, etc., using local materials and carried out under working conditions, which is not possible in a laboratory. Blocks made from one bag batches of sandstone and bluemetal concrete in the proportions of 1 : 2 : 4½, 1 : 3 : 6 and 1 : 4 : 8 were made in duplicate pairs, for both wet and dry mixes, one block of each pair being tamped in the usual manner and the other rodded with a pointed rod of small diameter. Eight inch cubes were then cut out from the large blocks, four cubes from each block and after dressing and facing were broken, when four months old, with the following results.

With dry batches "tamping" brought mortar to the surface and had a considerable compacting effect, while "rodding" appeared useless owing to the concrete being too stiff to flow back into the hole made by the rod.

With wet batches "tamping" was practically impossible and at most could only be done very lightly and with no compacting effect. "Rodding," however, seemed to have a pronounced compacting effect and brought clear water and air bubbles to the surface. This was particularly noticeable in the case of poor concrete.

For bluemetal concrete made in the proportions 1 : 2 : 4½ with 1½ in. metal for the large aggregate, the strength at four months obtained for a mix containing about 8 per cent. of water and "tamped" was 3,000 lbs. per square inch, while the same mix "rodded" gave 3,280 lbs. per square inch, an increase of about 10 per cent. Mixed in the same proportions, but using 10 per cent. of water, the strength when "tamped" was only 2,140 lbs. per square inch and when "rodded" 2,350 lbs. per square inch, the specimens of "rodded" concrete again showing an increase in strength of about 10 per cent.; the

specimens of wet concrete, however, showed only about two-thirds of the strength attained in the dry concrete.

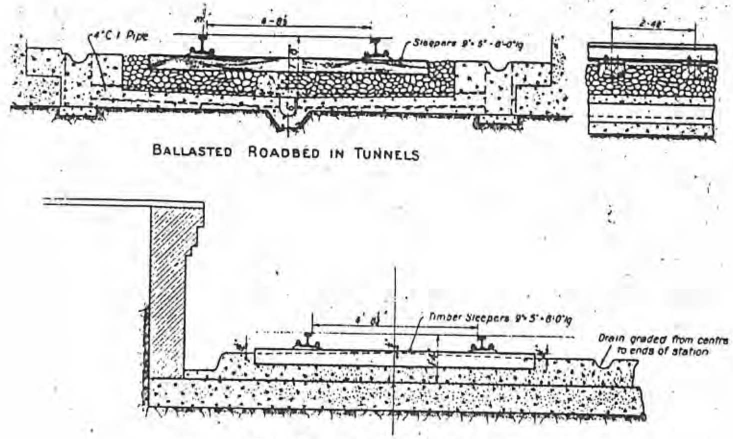
The tests of 1 : 3 : 6 bluemetal concrete made with 2½ in. metal, at the same age, 4 months, showed a compressive strength of 2,650 lbs. per square inch, dry, and 2,400 lbs. per square inch, wet, and no improvement was apparent in the case of the " rodded " concrete.

In the case of 1 : 4 : 8 concrete the number of blocks tested was too few to establish any decided difference between specimens of " rodded " and " tamped " concrete, nor was the difference between the strength of dry and wet concrete very marked, a strength of about 2,100 lbs. per square inch at 4 months for the dry and 1,950 for the wet being obtained. Generally speaking, the effect of the " rodding " was to increase the compressive strength of the concrete, the maximum increase obtained being nearly 20 per cent. " Rodding " gave better comparative results with wet mixtures than with dry, but did not compensate for the detrimental effect due to excess water. In no case did the rodding of wet concrete increase its strength sufficiently to make it as strong as the same concrete mixed with less water. " Rodding " for a longer period than in the above mentioned tests would, no doubt, further increase the strength, but is hardly practicable on most work, and any reduction in the quantity of cement used which had to be offset by a long period of " rodding " would not prove economical. On very wet work, " rodding " should be carried out to the fullest extent possible in order to compensate for the decrease in strength due to excess water, and give a concrete of normal strength. A combination of " rodding " and " tamping " proved most satisfactory.

The concrete mixing has been performed by one 16 cu. ft. steam-driven " Foote " mixer, three 10 cu. ft. electrically driven " Armstrong-Holland " and three 10 cu. ft. electrically-driven " Foote " mixers. The concrete is handled both in barrows and by chutes. The barrows are of the usual type, with a capacity of 5 cu. ft., while several types of chutes have been employed, both locally made and imported, that giving the most satisfactory results being the imported " Susby " Chute. This chute is of deep parabolic section, about 12 inches wide by 13 inches deep, and is obtained in lengths of 10, 20 and 30 feet, provided with suitable hoppers, swivel heads and plates. The mixers were worked under very heavy duty conditions, especially when pouring massed concrete behind the masonry-faced walls in Elizabeth Street and in the

abutments of the Hay Street Bridge. 2,340 cubic yards of concrete were poured in 19 days with one concrete mixer, which gave an average pouring of 123 cubic yards of concrete per day. One mixer of the " Armstrong-Holland " 10 ft. capacity type delivered up to 160 cubic yards in 8 hours, which is an exceptionally good record.

Trackwork.—It was specially desired to lay down a road bed which would need as little maintenance as possible and at the same time provide the essentials of a first-class track. With this ideal in view, certain new features have been introduced



BALLASTED ROADBED IN TUNNELS

CONCRETE ROADBED IN STATIONS

Fig. 37.—Types of Roadbed

which will be described for each type (see Fig. 37). At the present time, it is intended to lay down four tracks as far as Central station and two tracks from there to the City Terminal at St. James.

This involves a length of about 5 miles of single track of which one mile 62 chains is in tunnel. The rails being used are 100 lbs. A.S., supplied by Messrs. Hoskins Iron and Steel Company, of Lithgow. The steel used in the manufacture of these rails is by the C. P. Sandberg's " Basic Open Hearth High Silicon " process (5 C. Australian Standard Specification).

The fish plates are of the standard pattern for 100 lbs. rails, 30 inches long, with 6 holes to take the 1 in. diameter

bolts. These bolts are of standard pattern, from specially heat-treated carbon steel, while the phosphorus contained does not exceed 0.06 per cent. The heat treatment involves quenching the steel at a temperature of 1,472 Fahrenheit in an oil bath. The nuts are not quenched. Spring washers of $\frac{3}{8}$ in. x $\frac{1}{4}$ in. section are used for all fish bolts.

Ironbark timber sleepers in ballast have been adopted for the road bed in the open. The road bed in the tunnels is similar, with the ballast laid directly over a concrete base on the floor of the tunnels.

In order to minimise the presence of dust in the underground stations, as well as reducing the track maintenance, it was considered desirable to introduce a concrete road bed, with timber sleepers embedded therein. The sleepers are set into concrete, which will be kept 1 inch below the flange of the rail.

The sleepers are of ironbark—9 in. x 5 in. x 8 ft. long with 9 inch wide sleeper plates, $9\frac{3}{4}$ inches long at all bearings points. These are of steel made by the open hearth process and conform to the following requirements as to chemical composition.

Carbon shall be from 0.30 to 0.60 per cent.
Phosphorus shall not exceed 0.06 per cent.

This portion of the upper surface to take the rail flange is inclined to give the rail the usual cant of 1 in 20. Screw spikes with a diameter of $\frac{15}{16}$ in. and a length of 6 inches are used, instead of the usual dog spikes, to hold down the rail and sleeper plate.

The general spacing of sleepers is 2 ft. $4\frac{1}{2}$ in. centre to centre, allowing 18 sleepers to every 40 feet rail and slightly bunching the sleepers near the rail joint. Bridge plates have been provided at every joint and are of the same cross-section as the standard sleeper plate, but 2 ft. 6 in. in length. They constitute a support for the rail joint and have been found to be most effective in reducing the hammering action over the joint and also in preventing rail breakage.

Darling Harbour Reclamation.

The reclamation of that part of Darling Harbour extending up to Bathurst Street, an area of some 23 acres, was decided upon to provide for the disposal of the spoil from the City

Railway, the reclaimed area being added to the railway goods yard.

The filling-in of this portion of the harbour necessitated the provision of new circulating water intake for the Ultimo Power House. The new intake is being constructed from a point just beyond the reclaimed area on the western side of the harbour. The water will gravitate to the Power House through two 6 ft. diameter Monier pipes, laid in tunnel through rock, it being necessary to keep the soffit 6 inches lower than the lowest known tide, which is recorded as −3.6 standard Datum at the intake.

It has been found from conduits in present use that the area of the conduit will be reduced 3 inches all round by marine growth, but the long pliable weed which overlays the shell fish, makes an exceedingly smooth surface, so that if the diameter of the conduits is reduced by 6 inches, the friction coefficient may be taken as equal to sawn timber in the calculation for head required.

Although the two pipes will be required to deliver 100,000 gallons per minute, no spare pipe being provided, the marine growth can be removed periodically by choosing a slack time and running inefficiently for a short period.

The construction of the above tunnels was commenced with the sinking of two 9 ft. by 7 ft. shafts (numbered 4 and 3), one in William Henry Street and the other adjacent to Quarry Street. These shafts were sunk approximately 40 ft. to the invert level of the tunnel and drives pushed forward from both sides, through hard sandstone, the power for drilling being supplied by two air compressors. Electric light was installed throughout, and at the head of each shaft electrically-driven winches placed, for the handling of the excavated material, also electrically-driven fans were provided at both shafts. The same procedure was adopted at No. 2 shaft in Pyrmont Street and the large No. 1 shaft in Murray Street, in which are situated the screen chambers and silt wells.

As the filling up proceeded, the restriction of the head waters of Darling Harbour caused a certain amount of mixing of outlet water with the circulating water near the existing intake, with a resultant rise of temperature of the water at the intake. When about 5 acres had been reclaimed, the temperature of the circulating water on the intake side had risen some 20 degrees Fahrenheit and seriously affected the efficiency of the Power House. A coffer-dam, consisting of timber piles and walings with three thicknesses of 12 in. × $1\frac{1}{2}$ in.

sheeting, was therefore erected to act as a baffle and ensure the flow of the discharged circulating water from the vicinity of the intake. This has proved quite successful, and except for the maintenance of a channel for discharging the circulating water, filling in is proceeding without further inconvenience to the power house authorities.

It is proposed to carry all the drainage along the Sydney side of the harbour by a covered channel from Pier Street to Bathurst Street, with a branch to pick up the existing new conduits crossing the Darling Harbour Railway Yards, the 5 ft. by 4 ft. sewer from Pyrmont, and to raise the crown of the existing 10 ft. by 7 ft. sewer from Hay to Pier Streets along Lackey Street. This Lackey Street sewer is now used, during dry weather, to collect the sewage and waste waters reaching it from that part of the City areas which is too low to permit of interception by the Bondi sewer. The new covered channel consists of a duplicate conduit with an interior wall dividing the channel into 11 ft. 10 in. and 9 ft. 9 in. widths respectively with a depth of 7 feet, the object of the division being to keep the warm circulating water from the Power House separate. The channel is constructed in concrete. This section extends from the outlet as far as the junction of the power house discharge from which point a somewhat smaller section continues to the valve house and thence to Hay Street where the old section connects up to the new work. The flowline of the channel is taken out at the " King " tide, that is 12 in. above the mean ordinary high spring tides, and the invert at 12 in. below the mean ordinary low spring tides.

A feature of the layout of this intake is that, although the head required to deliver the water from the Harbour to the Power House is provided, the pipes are actually laid on a gradient towards the Harbour, the object being to facilitate cleaning, as it will be very easy to float the debris to the water front by pumping and lift it into a punt.

Lighting.

The lighting of the City Railway is provided by duplicate ring main systems at 2,200 volts, 50 cycles and 25 cycles, one main for Down and the other for Up tracks. These cables are taken underground at Prince Alfred Park substation and pass into a duct system, consisting of 3 in. diameter pipes set in concrete along the 6-track portion of the City Railway, as far as Campbell Street and thence by an open concrete track

along the side wall of the tunnels. At the various stations the lighting mains are looped out to transformers, which reduce the voltage to 240-120 volts, three wire, whence it is reticulated for lighting purposes at 240-120 volts A.C.

At Central station these transformers are of 100 kW., capacity each, while at Museum and St. James they are of 50 kW. capacity each. Emergency lighting is provided by a constant supply of 10% from the 25-cycle main, which would furnish sufficient light in the station, in case of a breakdown of the main supply.

The lighting of the tunnels will be purely for emergency purposes, lights being spaced about 20 feet apart and switches so arranged that lights can be switched on at one end and off at the other.

Power House and Substations.

As stated above, the power required this year is about 20,000 kW., while for the complete electrification of the inner suburban zone it amounts to something like 86,000 kW.

Turbo-generator units of size suitable for the development of the whole of the power required for the inner zone are being installed at White Bay Power House, with of course the necessary switch and control gear for these units included.

Power generated at 25-cycles 6,600 volts will be transmitted from Ultimo to the Prince Alfred Park substation, where it will be converted and supplied to the Sydney section of the City Railway at 1,500 volts D.C.

Meeks Road substation will receive power generated at 50-cycles 11,000 volts and convert portion to 1,500 volts D.C., while the remainder will be stepped up to 33,000 volts A.C. and transmitted to Hurstville, Sutherland and Waterfall Substations by the overhead transmission line.

Secondary Distribution.

For the City Railway the main centre of distribution is the Prince Alfred substation, where traction current at 1,500 volts D.C. is transmitted to the overhead catenary system, which is continuous and anchored in sections extending over half a mile

For the underground portion of the City Railway a catenary of stranded copper of 0.4 square inch section supports a cadmium bronze contact wire of 0.209 sq. in. section, the whole acting as a feeder system, with the catenary supported at 80 ft. intervals on double insulation and the contact wire attached by means of flexible hangers.

For the open air section, extending south from Campbell Street to the Suburban areas, a stranded copper catenary supports a contact wire of cadmium bronze having a sectional area of 0.209 sq. ins.

Between Central station and Campbell Street, the overhead structures are designed to act as signal bridges as well as supports for the catenary system. At the anchor structures, both the catenary and the contact wires are anchored.

To provide for traffic movements under all conditions, the line will be sectionalised and sectioning switches installed at convenient points.

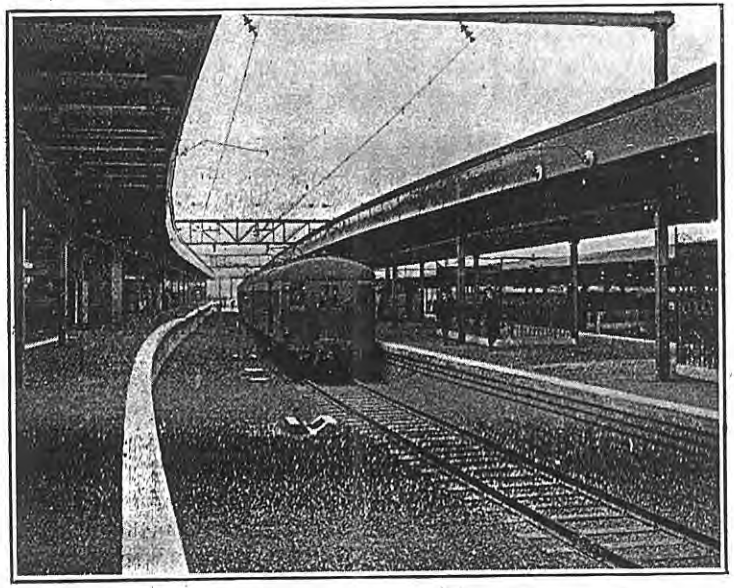


Fig. 38.—First Electric Train at Central Station.

Quantities and Costs.

As can readily be imagined from the foregoing pages, the bulk of the construction material and expenditure will be for Earthworks, Concrete, Steelwork, Brickwork and Masonry.

In preparing the estimates for these big items of expenditure the practice is to subdivide the costs into Wages, Material, etc. The working costs are kept strictly in accordance with the dissection laid down by the estimates, and it becomes possible to compare the working of costs of one period with those of another, and also with the estimate, with a full knowledge of the cause of any disclosed rise or fall in the costs per unit. The following schedule, Appendix I, shows the different types of construction with their attendant expenditure.

The following gentlemen have been the author's principal assistants, viz: Mr. Assistant Commissioner A. D. J. Forster, B.E., M.I.E. Aust., Principal Designing Engineer from 1916 to 1920; Mr. William Farrow, Supervisor of Construction; Mr. R. J. Boyd, M.E., M.I.E. Aust., Principal Designing Engineer since 1920; Mr. W. F. Burrow, M.I.E. Aust., Supervising Engineer; Mr. W. H. Ledger, B.E., M.C.E., M.I.E. Aust., Designing Engineer; Messrs. A. Humphries and K. A. Fraser, A.M.I.E. Aust., Resident Engineers; and Mr. E. A. Amphlett, B.E., A.M.I.E. Aust., Surveyor. To these and all other members of his staff, the author desires to express his thanks for their able assistance.

[The paper is illustrated by Figs. 1-38 in the letterpress and is accompanied by Appendix I.]

APPENDIX I.

Locality.	Construction.	Quantities.	Average Cost.	Total Cost. £	s.	d.
Central Station Museum Station St. James Station	Open Excavation including disposal of spoil	356,184 cubic yards	10.123 shillings per c. yd.	180,290	9	0
Tunnels under Hyde Park	Open Excavation including disposal of spoil	59,498 cubic yards	7.65 shillings per c. yd.	22,758	0	0
Tunnels between Goulburn Street and Museum Station Tunnels under Hyde Park Tunnels north of St. James	Tunnel Excavation including disposal of spoil and timbering	103,917 cubic yards	33.148 shillings per c. yd.	172,235	0	0
Eddy Avenue Bridge Hay Street Bridge Campbell Street Bridge	Open Excavation Bridge Pier and Abutments including disposal of spoil and timbering	14,492 cubic yards	20.82 shillings per c. yd.	15,086	5	0
Devonshire Street Subway Elizabeth Street Wall Walls between Hay and Campbell Streets Foundations between Campbell and Goulburn Streets	Open Excavation including disposal of spoil and timbering	32,227 cubic yards	19.88 shillings per c. yd.	32,034	8	0
Fly-over Crossings Devonshire Street Subway Central Station Eddy Avenue Bridge Hay Street Bridge Campbell Street Bridge Museum Station St. James Station	Reinforced Concrete and Concrete encasing steelwork	18,964 cubic yards	104.975 shillings per c. yd.	99,537	8	0

APPENDIX I. (*Continued.*)

Locality.	Construction.	Quantities.	Average Cost.	Total Cost. £	s.	d.
Cleveland Street Bridge Fly-over Crossings Devonshire Street Subway Central Station Eddy Avenue Bridge Elizabeth Street Wall Hay Street Bridge Walls between Hay and Campbell Streets Campbell Street Bridge Campbell Street to Goulburn Street Tunnels between Goulburn Street and Museum Station Museum Station Tunnels under Hyde Park St. James Station Tunnels north of St. James	Plain Concrete	83,188 cubic yards	56.68 shillings per c. yd.	235,779	5	0
Central Station Eddy Avenue Bridge Hay Street Bridge Campbell Street Bridge Museum Station St. James Station	Steel Reinforcing Bars	766 tons	£28.157 per ton	21,852	2	0
Fly-over Crossings Devonshire Street Subway Central Station Museum Station St. James Station	Riveted Steel	1478 tons	£32 per ton	47,296	0	0

APPENDIX I. (*Continued.*)

Locality.	Construction.	Quantities.	Average Cost	Total Cost. £ s. d.
Cleveland Street Bridge Fly-over Crossings Devonshire Street Subway Central Station Tunnels between Goulburn St. and Museum Station Museum Station Tunnels under Hyde Park St. James Station Tunnels north of St. James	Brickwork	18,335 cubic yards	67.216 shillings per c. yd.	61,620 2 0
Central Station Eddy Avenue Bridge Elizabeth Street Wall Hay Street Bridge Walls between Hay and Campbell Streets Campbell Street Bridge	Masonry	129,640 cubic feet	10.86 shillings per c. ft.	70,307 7 0

PART III.

ABSTRACTS OF PAPERS.

DISCUSSIONS AND COMMUNICATIONS.

MEMOIRS.